THE MEASUREMENT OF DRAUGHT RUMINANT ENERGY EXPENDITURE IN THE FIELD

JOHANNES T. DIJKMAN

PhD
UNIVERSITY of EDINBURGH
1993

DECLARATION

I, JOHANNES THEODORUS DIJKMAN, hereby declare that this thesis was composed by me and that the work described was my own.

CONTENTS

ABSTRACT

The aim of this work was to improve and validate the **Oxylog portable oxygen consumption meter** for use with draught ruminants, and to test its ability to estimate the energy expenditure of these animals in the field.

Few data were available on the energy costs of the various tasks that draught ruminants perform and it was expected that the calorific factors established during laboratory experiments may not necessarily reflect the energy consumption during field work with farmers. This could have important implications in the establishment of the nutritional requirements of draught ruminants.

A review of the literature on the various techniques and instruments available for the field measurement of energy consumption was carried out.

A new facemask for use with the Oxylog was designed and the Oxylog equipment with this mask was validated against the open circuit gas analysis system available at the Centre for Tropical Veterinary Medicine in Edinburgh. It was found that the Oxylog, on average, overestimated oxygen consumption, as measured by the gas analysis system, by 1.5 %.

In the second experiment, carried out with buffaloes and oxen pulling carts on the Unipalma oil-palm plantation in Meta, Colombia, the modified Oxylog system was tested in the field. Technically, the method worked satisfactorily, although the small digital displays on the Oxylog were difficult to read, and the measurements obtained generally agreed with the more established calculation methods of estimating energy consumption. It was concluded that the use of the modified Oxylog was an accurate and reliable method for the estimation of energy expenditure in the field. Insufficient

time, however, was available to train the animals to wear the facemask and to accustom them to the experimental procedures, hence, the acceptance of the mask was low. The use of a constant value for the energy cost of walking over various terrains and the difficulty in accurately defining the animals' respiratory quotient, were also thought to have affected the results.

In the third experiment, the influence of soil consistency on the energy cost of walking and the efficiency of working in Bunaji (*Bos indicus*) draught bulls in the sub-humid zone of Nigeria was investigated. These experiments were carried out in collaboration with the International Livestock Centre for Africa. A dataviewer was designed to facilitate data collection. To ensure that the respiratory quotient only varied between 0.8 and 1.0 the animals were fed 3 kg of concentrates, 1 h before the start of the experiments so that they were primarily metabolising carbohydrates. Eight experimental animals were trained over a period of four weeks and the mask acceptance rate was 100 %. The energy cost of walking on the different soils varied from 1.47 J/m/kg to 3.30 J/m/kg. Ploughing doubled or more than doubled the energy cost of walking on the soils investigated. Although the consistency of the soil did not influence the efficiency of doing work, both the speed of walking and working, and the distance average draught force were affected. A simple method to estimate the energy cost of walking based on the speed of walking on soils of different consistencies was proposed. It was further established that it would be more efficient to cultivate soils before they became inundated with water, because as they became wetter more time, effort and energy were needed for cultivation per unit area.

It was concluded that the modified Oxylog, although its use will be largely restricted to trained animals being investigated by research organisations, is a useful and reliable tool in draught ruminant field calorimetry.

ACKNOWLEDGEMENTS

My sincere thanks are particularly deserved by **Peter Lawrence**, who first set me off on the research path and who has been a great source of advice, encouragement and friendship throughout the duration of this project. He also made the first designs and necessary modifications to the flowmeter, valves and facemask which enables the Oxylog to be used for oxen and buffaloes. He further made and designed the open circuit gas analysis system used for the verification studies and worked out the operating and calibration systems used.

Anne Pearson and **Tony Smith** also deserve my heartfelt gratitude for their sustained encouragement and advice.

Richard Matthewman has been a constant companion in both work and social engagements over the past three years. The support given by him and his family has been invaluable.

Iain Campbell deserves thanks both for his friendship and hard work during the experimental period in Colombia and for his technical support at the Centre for Tropical Veterinary Medicine.

Unilever Plantations PLC and **Unipalma S.A.** are thanked for their financial support and for allowing me to carry out the experimental work in Colombia. Acknowledgements are further deserved by **Dr. R. H. V. Corley, John Noal** and all the staff of the Hacienda Santa Barbara for their personal support of the project in Colombia.

The financial support from the **International Livestock Centre for Africa** during my work in Nigeria and the use of their facilities is highly acknowledged. Personal thanks are deserved by **Hank Fitzhugh** for allowing me to carry out the research and **Doug Little** and all the Kaduna field staff for their constant support during my stay in Nigeria.

Bob Archibald, Paul Wright, Rhona Muirhead, Rick Clemence, Stuart Lansley, Jimmy Ramsay and **Bob Baxter** all deserve thanks for their technical support during the various stages of the experimental work.

Pauline McManus carefully prepared the layout of this thesis and deserves my thankfulness.

My sincere thanks and friendship is further deserved by all those people at the Centre for Tropical Veterinary Medicine and in Colombia and Nigeria who in one way or the other contributed to the successful completion of this work.

List of Abbreviations

ADAS	Agricultural Development and Advisory Service
ADF	Acid detergent fibre
ADP	Adenosine diphosphate
ARC	Agricultural Research Council
ATP	Adenosine triphosphate
CP	Crude protein
CTVM	Centre for Tropical Veterinary Medicine
DADF	Distance average draught force
DLW	Double labelled water
DM	Dry matter
DMI	Dry matter intake
E	Heat production (kJ)
eq.	Equation
E_w	Energy cost of walking
FAO	Food and Agriculture Organisation
FFB	Fresh fruit bunches
FM	Frequency modulation
FrM	Fresh matter
GE	Gross energy
HDF	harrowing dry fadama
HU	harrowing upland
HWF	harrowing wet fadama
ID	Integrate and display
ILCA	International Livestock Centre for Africa
LED	Light-emitting diodes
MAFF	Ministry of Agriculture, Fisheries and Food
ME	Metabolisable energy
MIC	Mobile indirect calorimeter
min	Minute
MRM	Metabolic rate monitor
n	Number of observations
NARS	National Agricultural Research Services

NDF	Neutral detergent fibre
NE	Net energy
NS	Not significant
OM	Organic matter
PDF	Ploughing dry fadama
PU	Ploughing upland
PVC	Polyvinyl chloride
PWF	Ploughing wet fadama
q	ME/GE (metabolisability)
R	Resting
RDP	Rumen degradable protein
RQ	Respiratory quotient
SA	Specific activity
SD	Standard deviation
s.e.	Standard error
SMR	Standing metabolic rate
STP	Standard temperature and pressure
TADF	Time-based average draught force
USA	United States of America
W	Body weight
WDF	Walking dry fadama
WPDF	Walking ploughed dry fadama
WPU	Walking ploughed upland
WPWF	Walking ploughed wet fadama
WU	Walking upland
WWF	Walking wet fadama
*	$P < 0.05$
**	$P < 0.01$
***	$P < 0.001$

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CHAPTER ONE
INTRODUCTION

Only 13 years ago draught animal research was considered a neglected subject (Smith, 1981a). However, the widespread failure of capital intensive mechanisation schemes in the tropics, combined with major shifts in the terms of trade in favour of the industrialised nations, have caused many policy makers to review their agricultural mechanisation strategies. The realisation of the continued importance of draught animals in major parts of the tropics, has stimulated interest in research. The rather gloomy perspective painted in 1981 has since been improved and many papers concerning the use, husbandry, health, training, implements and nutrition of draught animals have been published. Reviews by Petheram, Goe and Abiye Astake (1989) and Starkey, Sirak Teklu and Goe (1991) indicate the increase in institutes and organisations working on draught animals.

Traditionally, the feeding of draught animals was based on empirical knowledge and experience of the farmer. Some publications recommended up to 2.7 times the maintenance requirements for draught ruminants (Food and Agriculture Organisation [FAO], 1972; Goe and McDowell, 1980), others made no mention of the food requirements of draught ruminants (Agricultural Research Council [ARC], 1980). Knowledge of the energy expenditure and quantification of the nutrient requirements of such animals, under as wide a range of conditions as possible, is necessary to develop more efficient ways of employing draught animals and of making the best use of food resources available.

Much of the initial work which investigated energy metabolism of farm animals was associated with different aspects of digestion, metabolism and efficiency of food utilization as energy for maintenance, growth, pregnancy and lactation (Blaxter, 1962). This group of energy expenditures is relatively easy to study because the experimental subject normally stays in one place. Energy consumption, associated with movement and the performance of work by definition, involves taking complex measurements while the animal is in motion.

A large-scale scientific study on draught animals was carried out some 50 years ago by Brody (1945) in the United States of America (USA). His research mainly focussed on heavy horses, which were the most important draught animal in the USA. In recent years however, as interest in draught animal research has increased, more information on the energy costs of the different tasks that draught ruminants perform has become available (Ribiero, Brockway and Webster, 1977; Thomas and Pearson, 1986; Lawrence and Stibbards, 1990).

It is now widely accepted that values between 1.3 and 1.8 times maintenance are probably a better reflection of the real energy consumption of draught ruminants during the working day. It would be an under-statement however, to say that the requirements for draught ruminants can be quantified as easily as for other classes of ruminant livestock (Teleni and Hogan, 1989).

In parallel with research on energy expenditure *per se*, much research has been carried out to determine methods of measuring energy expenditure and it must be acknowledged that without the development of suitable instrumentation, the elucidation of energy expenditure would not have progressed so far (McLean and Tobin, 1987). In recent years sophisticated electronic equipment has reached the market, enabling greater precision in the measurement of animal and human metabolism. The main disadvantage has been that the majority of instruments are not portable. This means that when used for working animals, some arrangement such as a treadmill or circular race has to be constructed so that the animal can stay more or less in one place. This also precludes the animals doing any normal agricultural work such as ploughing and, although aspects of the natural environment such as soil condition and gradients may be simulated, the technique is restricted to the rather artificial and uncomplicated environment of the laboratory.

Over the years a number of scientists have tried several field methods (Lawrence and Pearson, 1989), but they have either proved to be too complicated, too inaccurate or too expensive.

At present, one of the methods most favoured for draught animals in the field is portable 'breath-by-breath' analysis. The instruments for this have been extensively used in human beings and no fewer than three systems have been developed in the past 20 years for use with large animals (Hornicke, Ehrlein, Tolkmitt, Nagel, Epple, Decker, Kimmich and Kreuzer, 1974; Howell and O'Neill, 1990; Clar, 1991).

In research started in 1987, by P.R. Lawrence with the help and collaboration of Mr. P.K. Morgan and Mr. Sullivan of P.K. Morgan Ltd., at the Centre for Tropical Veterinary Medicine (CTVM) of the University of Edinburgh, rather than developing yet another machine, it was thought to be possible to modify the Oxylog. This was an existing portable oxygen (O_2) analyser, which had been designed for use with human beings (Humphrey and Wolff, 1977) and which had proved both reliable in long-term field trials and accurate compared with laboratory methods (Harrison, Brown and Belyavin, 1982). Although problems were encountered in the manufacture of an airtight mask to fit the oxen, it was felt that the method showed many good points and that further development was warranted.

This thesis describes the further development and testing of the Oxylog instrument to measure O_2 consumption of working animals and its use to quantify the energy requirements of draught animals for work in different situations.

The thesis starts by giving a short background to direct and indirect calorimetry after which the various field methods available for measurement of energy expenditure are reviewed. The further process of adaptation and validation of the Oxylog for use in draught ruminants is described. Field trials carried out in Colombia, with buffaloes pulling carts in an oil-palm plantation, and Nigeria, where the influence of various soil conditions on the energy expenditure of Bunaji bulls for different activities was evaluated, are reported.

The thesis is concluded with an extensive discussion of the results and their implications on existing knowledge. Finally, recommendations for future research are made.

CHAPTER TWO
LITERATURE REVIEW

2.1 INTRODUCTION

At present it is readily accepted that conservation of energy is a fundamental principle of nature, but over 200 years ago this was not appreciated. The science that measures heat production is called calorimetry. Pioneers of this science were Crawford and Lavoisier who first measured the heat produced by an animal. It was Lavoisier who made the important breakthrough by recognising that the fundamental principle involved was the consumption of a new element 'oxygene'. It was not until 1866 that Pettenkofer and Voit demonstrated that metabolism could be interpreted in terms of the oxidation of protein, fat and carbohydrate (carbon-nitrogen balance). Rubner (1902), demonstrated that the values for the metabolism of fat and carbohydrate were the same as those measured in the bomb calorimeter, because the end products were the same. For protein, the value for metabolism was less since protein was only partially oxidised in the body and some of its energy was converted into the chemical energy of products excreted in the urine. Rubner (1902) later found complete agreement between the heat calculated from the indirect system of Pettenkofer and the heat measured by his direct calorimeter. Hence, there are potentially two ways in which to measure heat production; direct and indirect calorimetry.

In this literature review direct calorimetry and the problems connected with using direct calorimetry methods on animals in the field are explained. The theoretical background to indirect calorimetry is then discussed, after which the range of instruments and methods available for field measurements is described.

2.2 DIRECT CALORIMETRY

A direct animal calorimeter measures the total heat dissipated by the animal, and partitions the heat into its two components, evaporative and non-evaporative heat (McLean and Tobin, 1987). Modern day direct calorimeters employ the gradient layer technique (Pullar, Brockway and McDonald, 1967), in which the heat produced is allowed to flow through the walls of a sealed chamber. The temperature difference across the walls is electronically measured and integrated with respect to time to give the total heat production.

The results obtained in these chambers may be applicable to stall-fed animals, but they can hardly be applied to animals in the field. Even if it were technically feasible to measure the heat given-off by a working animal directly, there would still be a number of problems to consider:

1) Changes in enthalpy in breathed or in contact air are virtually impossible to measure in a free ranging animal.
2) Heat storage in the body of a working animal can be considerable, even if the core temperature does not change (McLean, Stombaugh, Downie and Glaseby, 1983).
3) Energy expended on the environment e.g. friction of an implement, is not directly measurable as heat.

The only direct method which proved useful in studies on the physiological aspects of exercise in humans was a calorimetry suit developed by Webb, Annis and Troutman (1972). The garment, a closely fitted network of small vinyl tubing, was worn under an insulating clothing layer. Direct measurement of heat dissipation was taken from the change in water temperature multiplied by the water flowrate. The water temperature was controlled automatically to keep the subject in a thermo neutral environment. The insulating clothing layer however, made it impossible to study the physiological or nutritional effects due to changes in the environment. Enthalpy changes in the breathed air were measured by careful weighing of the subjects, to determine the water loss.

2.3 THEORETICAL ASPECTS OF INDIRECT CALORIMETRY

Indirect calorimetry estimates heat production from quantitative measurements of the substances consumed and produced during metabolism. The method having the firmest theoretical base depends on the association between the heat produced by the consumption of metabolic fuel and the gaseous exchange. This measurement of metabolic heat production depends on two basic assumptions:

1) the end result of all biochemical reactions which provide energy in the body amount to the combustion of carbohydrate, fat and protein, to carbon dioxide (CO_2) and water (H_2O) and, in the case of protein, also to urea. CO_2 production and O_2 consumption are associated only with the above processes.
2) when oxidised in the body, there are fixed ratios between the quantities of O_2 consumed, CO_2 produced and heat produced, which are characteristic for carbohydrate, fat and protein (McLean and Tobin, 1987).

These assumptions, do not take into account that proteins may be broken down, giving a variety of urinary nitrogenous compounds other than urea, nor do they allow for bio-synthetic processes. The main bio-synthetic process, in the well-fed ruminant, is the production of fat from carbohydrates, but the heat output of such an animal can still be predicted (Blaxter, 1962).

Over many years of practical application, indirect calorimetry, when used in mature animals of fairly constant weight, has proved to be in close agreement with direct calorimetry (Rubner, 1894; Pullar *et al*, 1967).

Knowledge of the specific respiratory quotients (RQ) of carbohydrate, fat and protein , that is the volumetric ratio of CO_2 produced to O_2 consumed, and their heat production per l of O_2 used, can provide an accurate means of estimating the quantity of heat produced by measuring the gaseous exchange of a subject.

Over one hundred years ago the heat production of carbohydrate, fat and protein were determined by the results of their combustion in the bomb calorimeter (McLean and Tobin, 1987). The methods used to estimate the calorific factors are described below.

2.3.1 Carbohydrate

When carbohydrates are oxidised each molecule of O_2 used produces one molecule of CO_2, hence the RQ equals 1.

If for example 1 mole of glucose (molecular weight 180.2) is combusted in a bomb calorimeter, the empirical chemical formula for the reaction is as follows:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 2817 \text{ kJ}$$

During this combustion six moles of O_2 are used, occupying 6 x 22.41 l at standard temperature and pressure (STP). The ratio of energy released to O_2 consumed is 2817/(6 x 22.41) = 20.95 kJ/l or 0.746 l/g of glucose oxidised.

2.3.2 Fat

Most fats are triglycerides (esters of glycerol and three fatty acids). Animal fats include high proportions of palmitic and stearic acid. Vegetable fats are particularly rich in linoleic acid.

The combustion of palmitic acid in a bomb calorimeter may be taken as an example. It gives the following empirical chemical formula:

$$C_{15}H_{31}COOH + 23O_2 \longrightarrow 16CO_2 + 16H_2O + 10040\ kJ$$

The RQ = 16/23 = 0.696, and the ratio of heat released to O_2 consumed is 19.48 kJ/l.

The variation between the calorific factors is greater than with different carbohydrates. Nevertheless, the ratio of energy released to O_2 consumed is always within 19.4 - 19.6 kJ/l. The variation is further reduced because in the body several fats will be combusted at the same time.

2.3.3 Protein

Proteins, unlike fats and carbohydrates, are not completely oxidised to CO_2 and H_2O. The nitrogen is mostly converted into urea in mammals and as such is excreted in the urine.

The heat production however, can still be estimated from the separate heats of combustion. For example the oxidation of the amino acid alanine (molecular weight 89.094), gives the following empirical chemical formula:

$$4CH_3CH(NH_2)COOH + 15O_2 \longrightarrow 12CO_2 + 14H_2O + 2N_2 + 4 \times 1623\ kJ$$

The oxidation of urea (molecular weight 60.056), gives the following empirical chemical formula:

$$2(NH_2)_2CO + 3O_2 \longrightarrow 2CO_2 + 4H_2O + 2N_2 + 2 \times 634.6\ kJ$$

Subtraction of the two equations gives:

$$4CH_3CH(NH_2)COOH + 12O_2 \longrightarrow 2(NH_2)_2CO + 10CO_2 + 10H_2O + 5223\ kJ$$

The ratio of heat released to O_2 consumed is 19.42 kJ/l, RQ = 0.833.

The variations between these factors for different amino acids and the fact that proteins may be broken down giving a variety of nitrogenous compounds, are, as in fats, averaged out through the effect of mixing of amino acids. Hence, the amount of protein metabolised, as well as CO_2 produced and O_2 consumed, can be estimated from the measurement of urinary nitrogen.

2.3.4 Methane (CH_4)

Adjustments for the volumes of O_2 and CO_2 associated with CH_4 production have to be included when establishing the heat production of ruminant animals.

The combustion of CH_4 is expressed as:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O + 882\ kJ$$

CH_4 production by microbial fermentation in the rumen involves heat production. However, this process is essentially anaerobic and it cannot be estimated from the gaseous exchange. As far as the prediction of heat production from gaseous exchange is concerned, CH_4 production represents energy, O_2 consumption and CO_2 production that are not available to the animal. It represents a loss of 39.4 kJ of energy per l of CH_4 produced but it also means that 2 l less of O_2 are consumed and 1 l less of CO_2 is produced.

2.3.5 Algebraic analysis

This method is based on the algebraic analysis of the calculation procedures described in the above sections, and the only factors affecting the end result are the heats of combustion and the chemical composition of the metabolised products. The breakdown into the major categories is retained and the analysis can be extended to other substances if they are produced as end products of metabolism. This method is far more versatile than the calculation procedures described in Sections 2.3.1 to 2.3.4, and the heat production can be expressed as a simple linear equation using the data drawn up by Brouwer (1965):

TABLE 1

Data used for the determination of heat production in the body.
(after Brouwer, 1965)

	O_2 consumption (l at STP)	CO_2 production (l at STP)	Heat production (kJ)
Substance			
Fat[1]	2.013	1.431	39.8
Carbohydrate[1]	0.829	0.829	17.6
Protein[2]	5.98	4.84	114.8
Methane[3]	2.00	1.00	39.4

[1] Values / g oxidised to CO_2 and H_2O.

[2] Values / g of urinary nitrogen on oxidation to CO_2, H_2O and urea.

[3] Values / l at STP oxidised to CO_2 and H_2O.

If an animal is oxidising x g of carbohydrate and y g of fat then:—

Total O_2 consumption	VO_2 (l at STP)	= 0.829 x	+ 2.0123 y
Total CO_2 production	VCO_2 (l at STP)	= 0.829 x	+ 1.431 y
Total heat production	E (kJ)	= 17.6 x	+ 39.8 y

Elimination of x and y gives:

$$E = 16.16\ VO_2 + 5.09\ VCO_2 \qquad \text{(equation [eq.] 1)}$$

Using this formula and Table 1, oxidation of protein by an animal should produce 121.3 kJ/g of urinary nitrogen (U). In fact it produces only 114.8 kJ. In ruminants, which can produce substantial amounts of CH_4, the production of 1 l of CH_4 (VCH_4) represents 39.4 kJ of energy which the animal cannot use. This loss, calculated using eq. 1 is 37.4 kJ.

Incorporation of these discrepancies in eq. 1 gives:—

$$E = 16.16VO_2 + 5.09VCO_2 - 6.5\ U - 2.0VCH_4 \qquad \text{(eq. 2)}$$

In practice, for ruminants on high carbohydrate, low protein diets, the factors associated with urinary nitrogen and CH_4 production normally comprise less then 1% of the total heat production and their measurement is mostly ignored (Lawrence and Pearson, 1989).

2.3.6 RQ

From eq. 1 it can be seen that, if the RQ = 1, the O_2 factor accounts for more than 75% of the total value. If the RQ is known with some certainty the equation can be shortened and the heat production can be calculated from O_2 consumption alone.

However, RQ is not constant during the day (Figure 1). Theoretically, its value can vary between 1.3, when the animal is producing fat from carbohydrate at a maximum rate, and 0.7, when the animal is oxidising its fat reserves. In well-fed draught animals, the RQ varies between 0.8 and 1.0 (Lawrence and Campbell, 1987). Substituting an RQ value of 0.9 in eq. 1 leaves the following equation:

$$E = 20.7 \times VO_2. \qquad \text{(eq. 3)}$$

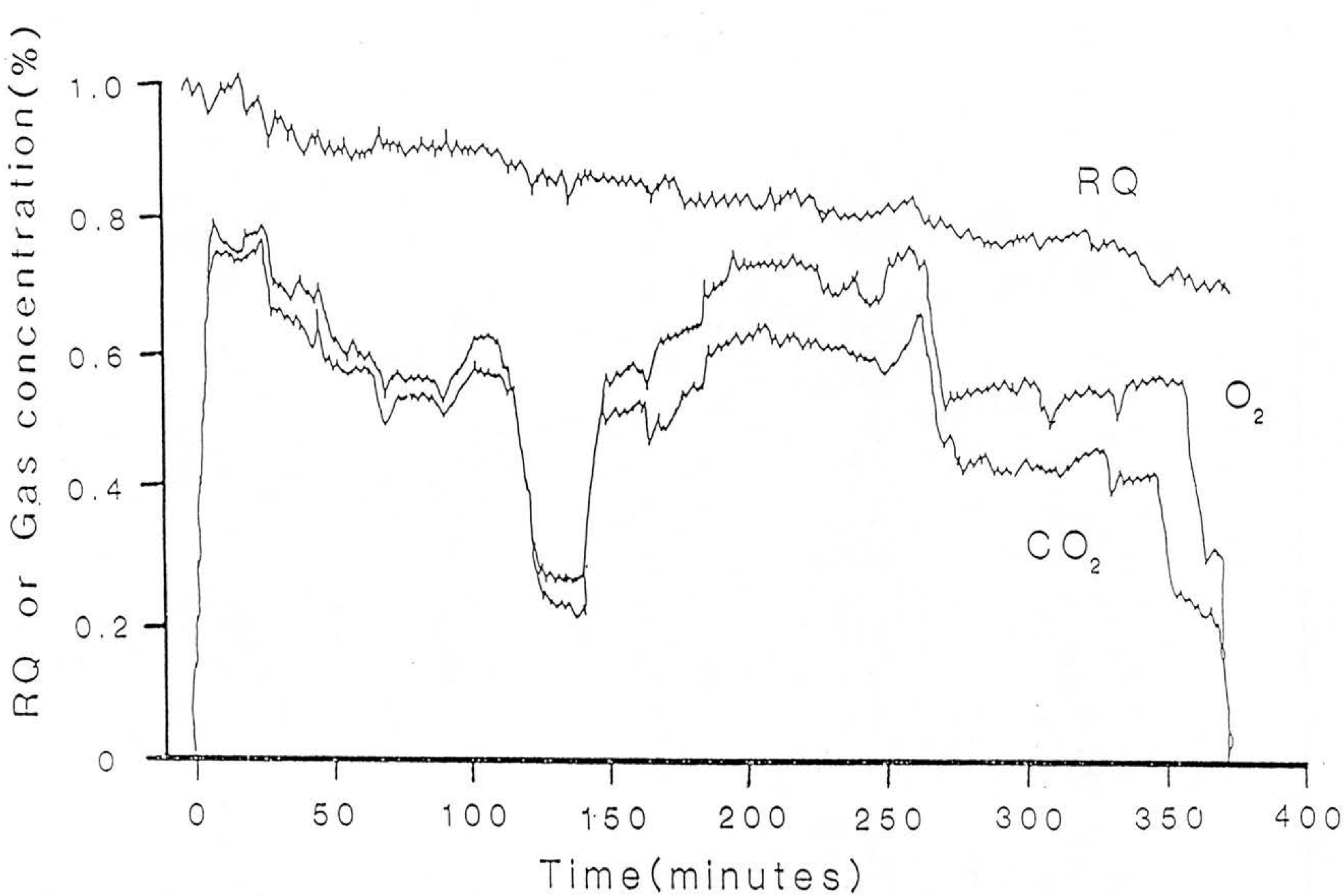


FIGURE 1

O_2 consumption and CO_2 production (as a percentage of total airflow) and RQ of a 450 kg ox during a day's work
(Lawrence and Pearson, 1989)

When only O_2 consumption is measured, the use of eq. 3 can lead to an over-estimate of heat production at the beginning of the day, because the animal is oxidising the carbohydrates from its morning meal (Figure 1), whereas measurements later in the day, when the animal is using its fat reserves as metabolic fuel, will lead to an under estimation. But a variation of 0.1 in RQ would cause only an error of $\pm 2.4\%$ in the estimate of heat production.

2.4 PRACTICAL LABORATORY METHODS OF INDIRECT CALORIMETRY

According to their operating principles, the methods of indirect calorimetry can be classified as; 1) confinement, 2) closed circuit, 3) total collection and 4) open circuit systems.

1) This method monitors the changes in gas concentrations in a sealed chamber.
2) This method measures the amount of O_2 that has to be replaced, as the animal is placed into or breathes into a sealed apparatus with H_2O and CO_2 absorbers.
3) This method collects all the expired air, after which total volume, as well as chemical composition, is determined.
4) This method is based on a ventilated flow-through system and has become the most popular method of indirect calorimetry.

In open circuit systems a stream of air is passed across the face of the animal via a mask, or drawn through a respiration chamber in which the animal is standing. The flowrate for any particular experiment is chosen so that the CO_2 concentration in breathed air does not exceed 1%, because this would stimulate respiration (Mountcastle, 1980). The measurement of the gaseous exchange requires determination of the amount of air flow and determination of the difference in the gas concentrations of the in- and outgoing air through the face mask or respiration chamber. The ingoing air is normally atmospheric air.

Outgoing air can be collected continuously or periodically into a reservoir or collection bag for later analysis, or can be sampled continuously for on-line analysis.

The gaseous exchange is calculated as the product of the air flow, the time and the average concentration difference for every gas monitored. The measured volumes can be used in calculations of heat production using eq. 2.

The open circuit gas analysis system available at the CTVM is typical in design of many systems. The relative freedom of movement, with open circuit systems, compared with the other systems mentioned, allows measurements to be made of animals working on a treadmill or in a circular race (Brody, 1945; Lawrence and Stibbards, 1990). The main disadvantage remains that the analytical equipment needed is not portable. This restricts the use of classic open circuit systems to the laboratory environment.

2.5 FIELD METHODS OF INDIRECT CALORIMETRY

Various techniques for the study of the energy expenditure of animals living outside have been tried by animal physiologists, with different degrees of success.

Brockway (1978), argued that a technique must meet the following standards:

1) The technique must respond equally well to every physiological stimulus causing a change in the metabolic rate.
2) The technique must estimate energy consumption to within $\pm 10\%$.

3) The technique must enable energy expenditure measurements over periods of 1 h or less.

4) The technique must involve minimal or preferably no surgical interference. If surgery is considered necessary the recovered animal should not be disturbed by it.

5) The technique must use equipment that is small, robust, lightweight and cheap if it is to be carried by the animal.

6) The technique must function for at least 24 h without attention (using automated recording equipment).

2.5.1 Portable open circuit systems

The first apparatus of this kind, for use with human beings, was developed by Zuntz, Loewy, Muller and Caspari (1906) (Plate 1). It was a forerunner of the Max Planck respirometer which was originally developed by Kofranyi and Michaelis (1940). In all machines developed for 'portable breath analysis', the subject inspired directly from the atmosphere. A non-return valve system mounted in the face mask, enabled exhalation into a separate outlet. In the apparatus of Zuntz *et al* (1906) the valve was operated manually at the bottom of a tube held in the mouth, in time with the subject's respiration. Some systems used a pump which automatically sampled the expired air at a constant proportion of the total flow, which was measured by a flowmeter. The sample was stored in a suitable bag or container and kept for later laboratory analysis (Douglas, 1911; Blaxter and Joyce, 1963).

Other systems measured the inspired volume, which avoided condensation problems in the flowmeter, and directly analysed each breath (Figure 2) (Humphrey and Wolff, 1977).

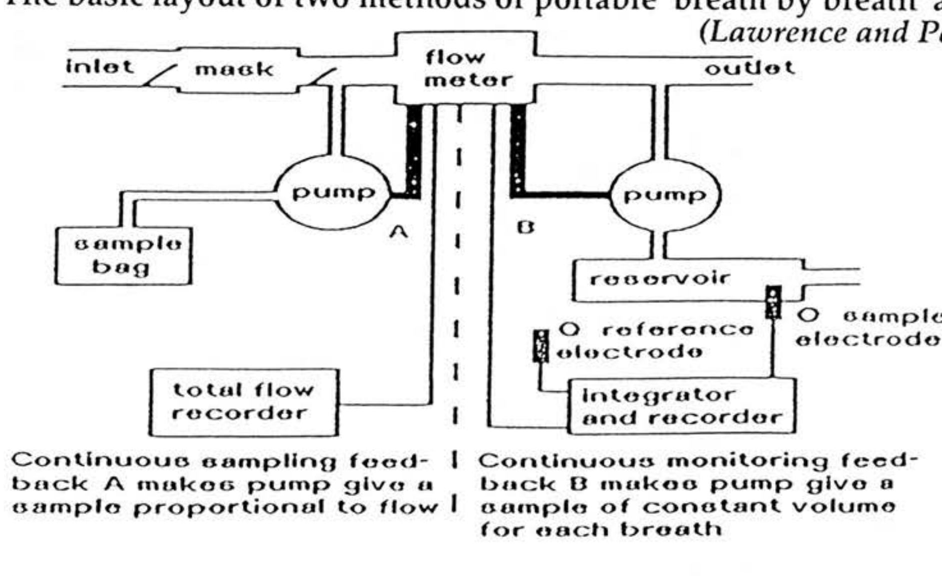
The collection of samples had the advantage that total chemical analysis for O_2, CO_2 and, in case of ruminants, CH_4 could be carried out, after

PLATE 1

First portable open circuit system developed by Zuntz *et al* (1906).

FIGURE 2

The basic layout of two methods of portable 'breath by breath' analysis.
(Lawrence and Pearson, 1989)



allowances were made for temperature, atmospheric pressure and humidity. It is however very difficult to monitor changes in metabolic rate, because each sample contains only an average concentration of the expired gases over the sampling period. The need for chemical analysis further restricts its use in the field to the vicinity of a laboratory because preservation of samples over an extended period is almost impossible.

Direct analysis has the disadvantage that it is usually possible to monitor one gas only, preferably O_2 (Section 2.3.6), but it offers a genuine field method and the possibility to monitor changes in metabolic rate.

Portable open circuit systems, normally employ one of two types of flowmeter; a pneumotachograph or a turbine flowmeter. The pneumotachograph is a tube-like flowmeter in which the drop in pressure is directly proportional to the flowrate (Poiseuilles law). This is because the viscosity of the inspired air, the length and the radius of the tube are constant.

The turbine flowmeter uses a two-bladed reflector mounted on a rotor. As air enters the flowmeter through an impeller, the linear airflow is transformed into a spiral airflow, which causes the reflecting blades to rotate. A light beam, usually infra-red, arranged to fall on the blades, is reflected to a photocell when it hits the reflecting blades in the correct angle. Electronic pulses taken from the photocell are thus directly proportional to the number of rotations of the blades and, by calibration, convertible to the flowrate of air through the turbine.

The pneumotachograph has the advantage of an unrestricted airflow, but its linearity tends to be affected during use because sedimentation of saliva and dust particles creates turbulence in the airflow reducing its reliability.

The accuracy of turbine flowmeters was reported to be variable (McLean and Tobin, 1987), but Ballal and McDonald (1982), noted agreement within 1 to 2% with a total collection system.

Partial O_2 pressure (concentration) is normally measured by polarographic cells, which work on the principle of electrolysis of solutions. These solutions, electro-oxidisable or electro-reduceable, are placed between a noble metal cathode and a reference anode. The amount of O_2 present in the analysed sample is directly proportional to the flow of current measured between the cathode and the anode. Electrodes need to be replaced regularly, but they are relatively cheap and have proved to be accurate (McLean and Tobin, 1987).

2.5.2 Examples of portable 'breath by breath' analysers

At present 'breath by breath' instruments appear to be the ones most favoured for use with draught animals in the field. Three systems have been developed in recent years.

Hornicke *et al* (1974) described the development of an apparatus used in horses in which the respiratory flow was measured by a strain gauge pneumotachograph and the partial O_2 pressure by a fast polarographic electrode housed in a thermostated block. The signals were transmitted by a Frequency Modulation (FM)/FM telemetry system and recorded on a magnetic tape (Figure 3). The response time of the O_2 electrode in this apparatus was of paramount importance, because the horse breathed both in and out through the flowmeter, which made averaging of gases in the expired air impossible. The pneumotachograph further suffered from the contamination problems discussed earlier (Section 2.5.1).

Howell and O'Neill (1990), described the development of a system in which the flow rate was measured by a heated pneumotachograph, thereby

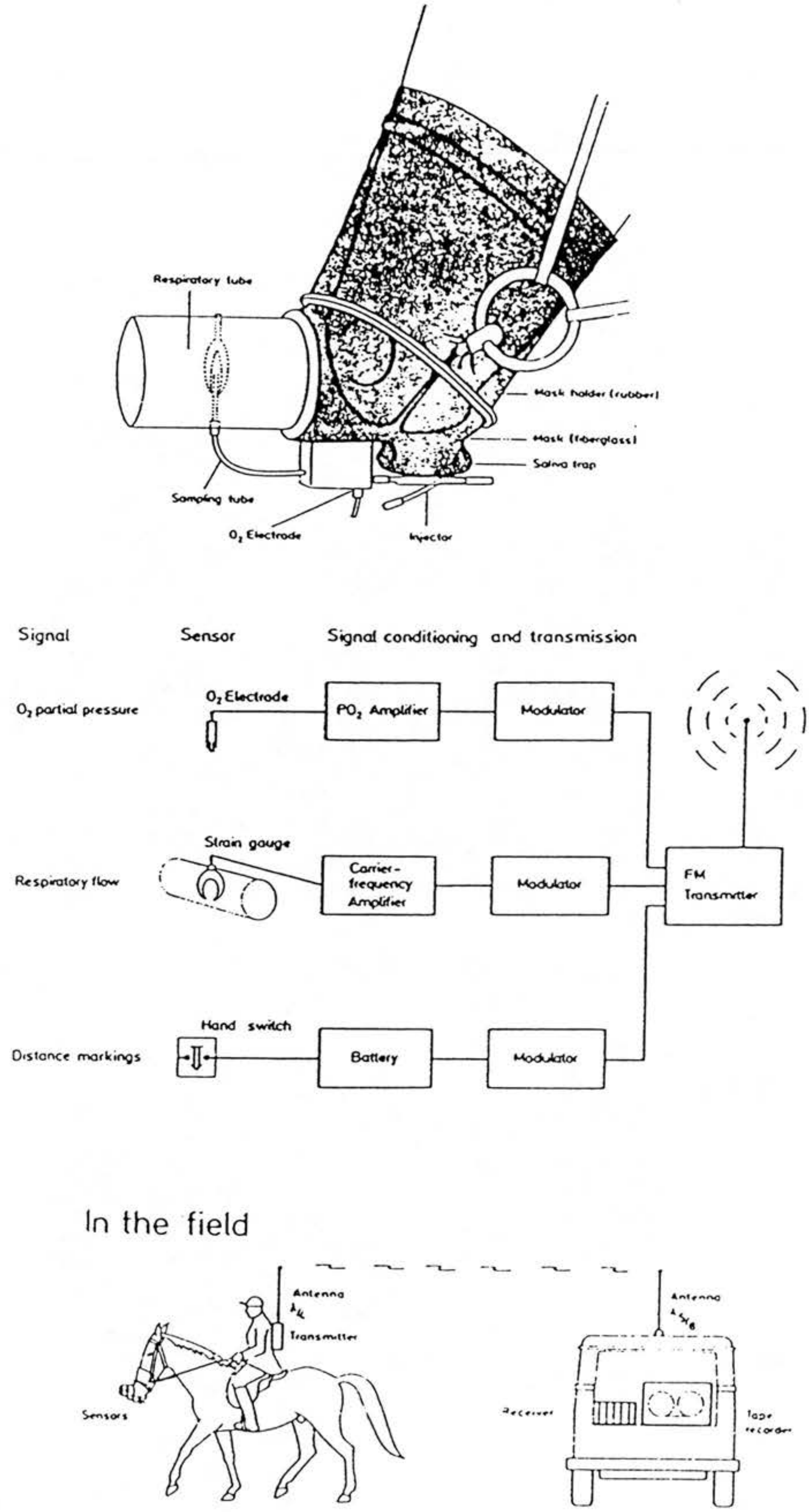


FIGURE 3

Portable 'breath by breath' instrumentation developed by Hornicke *et al* (1974).

avoiding problems caused by the condensation of H_2O vapour from the animals' breath. Samples of expired air were passed over polarographic O_2 electrodes in a small reservoir, which at any time contained samples from several previous breaths. The size of the reservoir was chosen in such a way that the O_2 concentration changed sufficiently slowly for the electrodes to follow it accurately. Signal processing and collection of data were done by a microprocessor based data logger which formed part of the portable apparatus. Total airflow and O_2 consumption were calculated by a computer after the data had been off-loaded.

Clar (1991), at the University of Hohenheim, developed an apparatus which used a mask made from transparent polyvinyl chloride (PVC) modelled on a cow's head. It had one inlet valve (45 mm) on either side of the mask and a larger outlet valve (60 mm) in the middle. A PVC cap at the bottom of the mask could be opened to let out saliva and condensation. The mask was strapped to the animal's head using a close fitting adapter. Between 2 and 3.5% of the total expired air was drawn from a gas meter by a pump and stored in an aliquot collection bag. CO_2 and O_2 concentrations in the samples were obtained by measuring their partial pressure with a blood gas analysis system.

All the above mentioned techniques have shown major drawbacks to their actual use in the field. Apart from the technical problems mentioned, they were very difficult to adapt to animals of different sizes, they were expensive, they required a large and complicated back-up system (Hornicke *et al*, 1974), they had major problems with the storage of samples which meant that the method could not function out of the vicinity of a laboratory with a blood gas analysis system (Clar, 1991). As a result, none of these methods have been used on a wider scale, and the development of a simpler, more user-friendly portable breath analyser seemed warranted. Research started in 1987 at the CTVM of the University of Edinburgh, approached the problem differently. Rather than develop yet another machine it was thought to be possible to modify an existing portable O_2 analyser, the Oxylog (P.K. Morgan Ltd., Kent, U.K.). This apparatus was originally designed for use with human beings (Humphrey and Wolff, 1977). It had proved reliable in long-term field trials and was accurate when compared with laboratory methods (Harrison *et al*, 1982). Its basic functions were measurement of ventilation volume, collection of a representative sample of mixed expired air and subsequent gas analysis to determine the inspired/expired concentration difference. The subject wore an airtight face mask which had an inspiratory valve with an incorporated turbine flowmeter and thermistor, and an expiratory valve. Expired air was led via a hose into a mixing and by-pass unit from which a double piston pump drew a sample for analysis by a polarographic O_2 sensor. A second electrode measured the partial pressure of O_2 in the atmosphere. Drying of the samples, before analysis, was achieved by passing them through anhydrous calcium sulphate. The O_2 consumption was calculated directly by suitable electronic circuits, from the inspired volume (measured by the flowmeter) and the O_2 differential, after making corrections for STP, while a relative humidity of 0.5 was assumed. Values for relative humidity other than 0.5 had to be accounted for, as they introduced error in the calculations (Dounis, Steventon and Wilson, 1980). Dijkman (1989) described that it was possible to manufacture scaled-up versions of the turbine flowmeter and to increase the capacity of the valves. Problems were encountered in the manufacture of a mask to fit the oxen. Attempts to make the mask airtight around the animal's face using cling film coated rubber foam proved unsatisfactory. The method however showed many good points and further development of the Oxylog for use with draught ruminants is described in Sections 3.3.1 and Chapter 4.

2.5.3 The metabolic rate monitor (MRM)

This instrument, a portable flow-through meter, designed by Webb and Troutman (1970), has been found to be accurate in the continuous measurement of O_2 consumption in humans, and may well prove useful in the measurement of O_2 consumption of draught ruminants in the field.

The MRM consisted of a mask through which air was drawn by a pump located at the end of a flexible hose. The speed of the blower was controlled by a feedback loop from an error signal. The signal was developed by comparing the output by the polarographic O_2 sensor in the pump housing with a preset reference signal, normally equivalent to a concentration difference of 1%. If the downstream O_2 concentration decreased, the difference between the two signals got bigger than 1%. This error signal was then amplified and used to control the blower, whereby the volume flow was adjusted, returning the downstream O_2 concentration to its preset value (Figure 4). Hence, the flowrate was directly proportional to the O_2 consumption (flowrate x 0.01 = O_2 consumption). The slight negative pressure in the mask eliminated the need for airtightness, which is a prerequisite in the previously discussed portable methods of measuring O_2 consumption. The absence of valves also overcame the possible problem of restriction in the passage of breath. Its accuracy in the field however, might be reduced by wind blowing into the mask. The MRM did not measure ventilation volume, nor did it show the volume of O_2 on a 'breath by breath' basis. It did give a time average over several breaths, fast enough to follow a change in O_2 consumption. This offers another advantage in its potential use, because, as pointed out by Lawrence and Pearson (1989), panting would greatly reduce the accu-

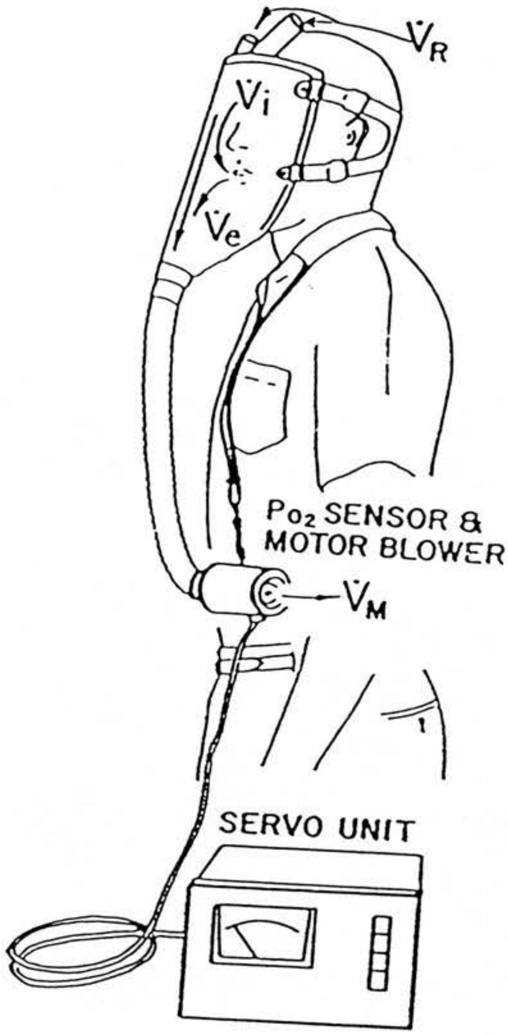


FIGURE 4

The MRM developed by Webb and Troutman (1972).

V_R = Air entering the system
V_i = Inhaled air
V_e = Exhaled air
V_M = Mixed air emerging from motor blower

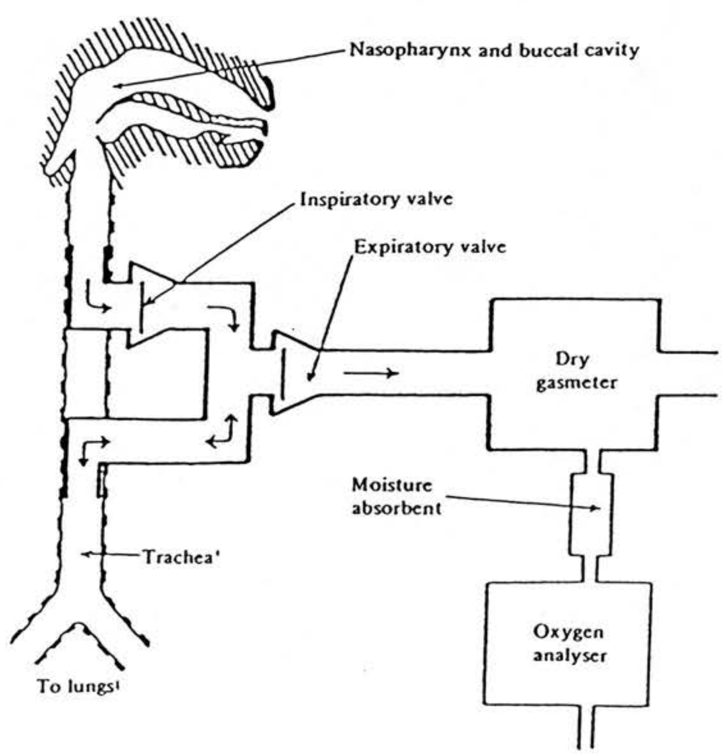


FIGURE 5

Tracheal cannulation method developed by Young and Webster (1963).

racy of total O_2 consumption measurements on a 'breath by breath' basis by a conventional portable open circuit system. Panting animals have high ventilation rates, whereas changes in concentration of both CO_2 and O_2 are only marginal. The measurements of O_2 consumption by the MRM however, was unlikely to be affected by this.

2.5.4 Tracheal cannulation

Young and Webster (1963), described a technique to measure O_2 consumption in grazing animals by double fistulation of the trachea. This was an improvement on previous methods which employed systems which bypassed the nasopharynx, thereby disturbing the processes of smelling, communication and thermoregulation (Flat, Waldo, Sykes and Moore, 1958; Cresswell and Harris, 1961). They designed an endotracheal flow divider which permitted normal inspiration, whilst exhalation was done through an expiratory valve (Figure 5). Expired air was led via a flexible hose to a flowmeter which was mounted on a small two-wheeled cart pulled by the animal. Here a pump automatically collected 0.3 or 0.6% of the air passing through the meter which was stored in suitable containers, also present in the cart. The method has been used by Corbett, Leng and Young (1969) to study energy expenditure of grazing sheep. This equipment, referred to as 'mobile indirect calorimeter' (MIC), was known to underestimate O_2 consumption and CO_2 production by about 20% (Corbett *et al*, 1969) relative to open circuit gas analysis. Even if this was improved, the technique has to be regarded as unsuitable for use with draught animals in the field, because it involved surgery and is ethically questionable with regard to the animal's welfare, which would be unacceptable on farmers' animals. Brockway (1978) pointed out that it would shorten the life span and greatly restrict the number of experimental animals on which measurements could be performed. The method was also likely to impair respiratory thermoregulation and respiration which would further reduce the validity of the measurements.

2.6 TRACER METHODS

2.6.1 Carbon dioxide entry rate

The first proposition to use the CO_2 entry rate to measure the energy expenditure of farm animals in the field was made by Young, Leng, White, McClymont and Corbett (1969). White and Leng (1968), had presented evidence for the closeness of the relationship of CO_2 expiration and the rate of energy expenditure, with CO_2 entry rates of restrained lambs. This involved the measurement of CO_2 production by an isotope dilution procedure in which the rate of formation within the body, rather than its rate of elimination by the lungs, was the primary method. The technique was based on infusion of radioactive $NaH^{14}CO_3$ at a constant rate. Once an equilibrium with the body pool of CO_2 had been reached, the CO_2 entry rate was calculated from the ratio of the infused radioactivity to the specific radioactivity (SA) of the CO_2 in the expired air, blood, saliva or urine. Young (1970), argued that CO_2 appearing in the urine probably gave the best value for the SA, its continuous excretion providing a representative sample for the entire period of collection. Furthermore, urine samples were relatively easy to obtain in the field, although an instrument developed by Farrell, Corbett and Leng (1970) allowed continuous automatic sampling of blood.

Whereas White and Leng (1968), Young *et al* (1969) and Corbett, Farrell, Leng, McClymont and Young (1971), were able to predict energy expenditure to within 15 - 20% of simultaneous gaseous exchange measurements, they also stated that the entry rates obtained were not necessarily a precise measure of the body's total production of metabolic CO_2, but rather a function of it.

Brockway and Whitelaw (1970) and Whitelaw, Brockway and Reid (1972), however, refined the method and were able to predict the CO_2 production within 2 to 4% of measurements made with gaseous exchange. They concluded that the CO_2 entry rate derived from 24 h collection of urine could provide a reliable estimate of the total CO_2 production.

Whitelaw (1974), argued that results of previous workers were entirely based on their inability to achieve some measure of equality between the CO_2 production and the CO_2 entry rate, but that this was largely due to the period they allowed for equilibration of the infused radioactivity with the body pool of CO_2. The former is not homogeneous and physiologically consists of several interlinked pools, which can either 'fix' some of the radioactive CO_2 or have very low turnover rates. The most likely site for this to occur is the skeleton, as bone contains many carbonates.

Although Whitelaw *et al* (1972), stated that their preliminary infusion period of 12 h was insufficient for equilibration with the total body stores, they considered it better to make an allowance for the slight overestimate rather than to spend the extra time and costs needed.

A further source of error made by Corbett *et al* (1971) was the use of the MIC for simultaneous gaseous analysis, which underestimated the O_2 consumption and the CO_2 production by about 20%, relative to chamber measurements (Corbett *et al*, 1969). Whitelaw (1974), therefore suggested that experiments designed to examine the relationship between CO_2 entry rate and production should at least meet three requirements:

1) There should be sufficient time for equilibration (12 h).

2) Measurements should be made over long periods to minimise the effect of temporary changes in body CO_2.

3) Equipment used for simultaneous gaseous analysis should have a proven accuracy.

One major drawback on the use of this technique in working animals is the slow turnover rate of the CO_2 pool (1 to 2 h), compared with the rate at which metabolism can alter (Lawrence and Pearson, 1989). This means that care has to be taken that during the sampling period the metabolic rate is relatively constant.

To overcome the problem of continuous and precise infusion of $NaH^{14}CO_3$, White and Leng (1968) developed a single injection procedure. Though it was much easier to administer labelled CO_2 in this way, it had the disadvantage that the decline in SA of CO_2 must be determined precisely in many samples of body fluids and the mathematical analysis of the results was very complex. Furthermore, the rapid elimination of $^{14}CO_2$ by the lungs made it only useful for short term measurements. Developments made in the routine infusion of radioisotope into adult sheep (Young *et al*, 1969), were used successfully by Havsted and Malechek (1982) to compare the energy requirements of free ranging animals with stall fed animals, on a similar diet.

Recently Sahlu, Hart, Klein, Jacquemet and Carneiro (1992) described the use of $^{13}CO_2$ to estimate CO_2 production and energetic requirements of free ranging goats. ^{13}C is a naturally occurring non-radioactive isotope, and as such has no restrictions on its use. However, it had its drawbacks in that it was more expensive than ^{14}C. Nevertheless, results for the prediction of the CO_2 production are encouraging and more research into this method seems to be justified.

2.6.2 The double labelled water (DLW) technique

Lifson, Gordon and McClintock (1955), first described using double labelled water ($^2H_2{}^{18}O$) to measure total CO_2 production in an animal. Their method was based on the finding that the O_2 of respiratory CO_2 was in isotopic exchange equilibrium with the O_2 of body H_2O (Lifson, Gordon, Visscher and Nier, 1949). Deuterium (^2H) is removed from the body almost entirely as ^2H_2O, $^{18}O_2$ however, is also lost as respiratory CO_2 and hence the turnover rate of O_2 in the body is greater. The difference in the two rates of decrease multiplied by the volume of the total body H_2O (which may be estimated from the initial equilibrium SA), will give the rate of loss of CO_2. Lifson and McClintock (1966), described the simplifying assumptions made to derive equations for the H_2O and CO_2 output as follows:

1) The animal is in a steady state of body composition: body H_2O remains constant as does the weight and composition of body solids.
2) All rates of intake and output remain constant.
3) All body H_2O is equally labelled and there is no incorporation of labelled hydrogen (H) or O_2 into other body constituents than CO_2.
4) H_2O and CO_2 lost from the body have a SA equal to those in body H_2O.
5) No H_2O or CO_2, either non-isotopic or isotopic, enters the body with inspired air or through the skin.

The assumptions indicated that under any real conditions some error would always result. Nevertheless, the DLW method has since been validated by different authors in adult humans (Schoeller and Van Santen, 1982; Schoeller and Webb, 1984), and more recently in infants (Jones, Winthrop, Schoeller, Swyer, Smith, Filler and Heim, 1987).

From the point of view of the experimental subject, the DLW method is both simple and non-invasive and neither of the isotopic labels, as compared with the CO_2 entry rate technique, is radioactive. Study procedures involved sampling of body H_2O i.e. blood, urine or saliva, shortly after equilibration of the administered isotopic loading dose and at the end of the study. The isotopic disappearance rates were determined from the isotopic enrichment of these two samples. Schoeller and Webb (1984), used the technique in a five day study in humans and found that the differences with concurrent gaseous exchange measurements were larger than in previous studies. This was mainly due to the shorter metabolic period which reduced the precision with which isotope elimination rates could be determined. This emphasised the fact that the method can only be used for long term determinations (e.g. 14 days).

Although the method looks very promising for use in draught animals, some of the basic assumptions made are not compatible with the physiology of ruminant animals and other problems arise because of the generally large size and high levels of activity of these animals, which may affect the validity of the technique.

The DLW method relies on the postulate that H is lost from the body only as H_2O. The ruminant animal however also loses H as CH_4 which is a by-product of microbial fermentation in the rumen. Midwood, Haggarty, McGaw, Robinson and Fuller (1989) found that the CH_4 produced by sheep given H_2O enriched with ^2H contained only 0.6536 as much ^2H per H atom as the urine over a wide range of CH_4 production levels. They were thus able to formulate equations which permitted the calculation of CO_2 production, provided that reasonable estimates of CH_4 production could also be made. Omission of the CH_4 correction factors would have led to underestimates of

CO_2 production from 3.3 to 6.5%, depending on the CH_4 production level. Another source of error is caused by differential fractionation of isotopes during any physical or chemical equilibrium process involving H_2O. Chief among these processes are the evaporation of H_2O during insensible perspiration, the equilibration of O_2 between H_2O and CO_2 and the evaporation of H_2O from the respiratory tract. Whereas most of these can be linked to the CO_2 production, the factor having the largest quantitative effect, the respiratory evaporation of H_2O, can pose problems. This quantity correlates fairly well with CO_2 production in non-panting animals in temperate climates (Haggarty, 1991), but it is unlikely to do so in draught animals in the tropics. Evaporative H_2O loss could be measured by introducing a third isotope into the H_2O. Haggarty, McGaw and Franklin (1988), proposed the use of H_2O labelled not only with ^2H and ^{18}O but also with either tritium (^3H) or ^{17}O. ^3H is the cheaper option although it has the disadvantage of being slightly radioactive. In the body the different isotopes fractionate to different known extents between the liquid and vapour phases during the evaporation of H_2O. In the case of ^3H, therefore, the change in the ratio of ^2H to ^3H in the body can be used to assess the rate of loss of H_2O by evaporation, which in turn can be used to correct for the differential fractionation of the ^2H and H isotopes during the same process. Incorporation of isotope into proteins, or more importantly, fats (Haggarty, McGaw, Fuller, Christie and Wong, 1991) can adversely affect the DLW method, although this is unlikely to be of importance in mature draught animals. The possibility of the amount of total body H_2O at the beginning of an experiment being different from that at the end owing to factors such as dehydration is likely to be of more importance.

Apart from the technical problems, the main practical one remains the cost of the labelled water. Although the introduction of high precision mass spectrometers over the past 10 years has reduced the required dose and hence the cost of isotope needed, it is still expensive. Dosing one ox would cost about US $ 1,000 in 1993. As long as this barrier remains, the extensive research needed to validate the technique for use in draught animals seems unlikely.

2.7 HEART RATE AS AN INDICATOR OF ENERGY EXPENDITURE

Over the past 50 years, various attempts have been made to use heart rate as a measure of energy metabolism in farm animals.

The theory of a relationship enabling O_2 consumption to be predicted from heart rate, was first described by Brody (1945) in working horses. He gave a general formula, indicating that O_2 pulse (O_2 consumed per heart beat: O_2/f) was directly proportional to body weight (W): $O_2/f = 0.05 \times W$. He further stated that if the O_2 pulse to body weight index was 0.05, the animal probably had an average work capacity. Higher or lower values would indicate a work capacity above or below the average.

Webster (1967), carried out experiments in which he exposed sheep to fluctuating environments, 'similar' to those that they might experience in the field. A comparison of the established individual 'calibration equation' (O_2 consumption/heart beat), with simultaneous gaseous exchange measurements, resulted in errors ranging from ± 8.6 - 13.8%. He also reported that in some animals it appeared to be impossible to establish a relationship between O_2 consumption and heart rate.

Brockway and McEwan (1970), found no relationship in sheep, whose metabolic rate was raised in response to cold stimulus and stated that the six month training period, before estimates of O_2 consumption and heart rate were made, was insufficient to overcome emotional disturbances affecting the relationship. They therefore concluded, as Brockway and Whitelaw (1969) did, that prediction was valueless, if not impossible. They also pointed out that even when animals were calibrated, they may not show the same relationship in the field as in the laboratory.

Holmes, Stephens and Toner (1976) however, studying the relationship in calves kept out-of-doors, argued that measurement of heart rate could provide useful information about the energy metabolism of free ranging animals. The methods they used were rather doubtful, because the animals were calibrated after a two day training period and only using CO_2 production/heart beat. As CO_2 production represents approximately 25% of the total heat production value in eq. 1, the absence of subsequent measurements of the RQ in their experiments left rather large margins of error.

Yamamoto, McLean and Downie (1979), were able to predict heat production from heart rate in cattle within 10% and they stated that, provided each animal was calibrated individually, frequent measurement of heart rate could offer a practical method for the prediction of heat production of animals in the field.

In most of the above mentioned work, increased heart rates were either induced by a thermal stimulus or a result of increased metabolism after eating. Richards and Lawrence (1984), were able to give a general formula for the prediction of energy metabolism in regularly trained and highly fit draught animals, when heart rate and energy expenditure were expressed relative to their respective resting values:

$$EE = 24.94\,R - 16.25$$

where EE = energy expenditure in watts/$kg^{0.75}$

and R = heart rate of working animal/heart rate at rest

Differences compared with values obtained by other workers were explained by the timing of heart rate measurement (postprandial — preprandial) and the observation that working animals undergo an increase in heart rate in addition to that necessitated by the increase in metabolism, due possibly to nervousness or increased muscle tone.

Later workers found similar relationships in smaller animals (Sneddon, Mathers and Thomson, 1985) and in animals exposed to different ambient temperatures and rates of energy expenditure (Sneddon, 1986). This confirmed that between animal differences were reduced when heart rate and energy expenditure were expressed in relative terms. Nevertheless, the formula is only a general one and it is often possible to obtain better correlations if individual calibration of the animals concerned is carried out.

A problem in applying this method in the field is the difficulty in assessing a basal heart rate, because of fluctuations due to e.g. recovery from previous work, anticipation of work to come, as well as, the possible influence of training or increased fitness. Furthermore, it is technically very difficult to measure precisely all heart beats of ruminant draught animals using electrocardiography for an extended period, because accumulation of sweat can dislodge the electrodes and muscle action potentials can interfere with the electrical recording apparatus. Recording can further be obstructed through the presence of subcutaneous fat (Richards and Lawrence, 1984).

2.8 MEASUREMENT OF WORK OUTPUT BY RUMINANT DRAUGHT ANIMALS

Whereas the measurement of energy expenditure is of prime importance in the quantification of the nutritional requirements of farm animals, the extra energy requirements of draught animals derive mainly from the work these animals perform. The most fundamental measurements taken from draught animals in this respect are those of the draught force and the distance walked. Such measurements allow agriculturalists and veterinarians to find out how much work (Force [N] x Distance [m]) draught animals are likely to do and at what cost in energy and food. These measurements are also needed by engineers to design better implements and harnesses. Traditionally, the force exerted by draught animals whilst pulling loads has been measured using a dynamometer (Kruger, 1957; 1958). This instrument connects the animal and the load it pulls so that the reading given is proportional to the force exerted. Since this force under field conditions varies considerably, dynamometers usually give a time-based average draught force (TADF) over a short period of time (usually 2 to 5 sec). TADF is useful if one wants to investigate the stresses experienced by harnesses and machinery. Such averages however, cannot be used as a basis for the work done by draught animals since both the speed and draught force of such animals working under field conditions vary continuously. This point is illustrated by situations A and B postulated in Table 2 from which it can be seen that work output can only properly be calculated if draught force is integrated with respect to distance rather than time (distance based average draught force [DADF]) (Lawrence and Pearson, 1985).

TABLE 2

The effects on time- and distance-based average draught force of variations in speed and load.

Situation A. *Consider an ox pulling with a force of 200 N for 10 s at a speed of 1 m/s, followed by 400 N for 10 s at 0.5 m/s.*

Situation B. *Consider an ox pulling 200 N for 10 s at 1 m/s followed by 100 N for 10 s at 0.5 m/s.*

	A	B
Distance travelled in first 10 s (m)	10	10
Distance travelled in second 10 s (m)	5	5
Work done in first 10 s (J)	2000	2000
Work done in second 10 s (J)	2000	500
Total distance travelled (m)	15	15
Total work done (J)	4000	2500
DADF (N)	$\frac{4000}{15} = 266.7$	$\frac{2500}{15} = 166.7$
TADF (kg/s)	$\frac{200+400}{2} = 300$	$\frac{200+100}{2} = 150$

N.B. In Situation A TADF overestimates the true draught force and in Situation B it underestimates.

(Lawrence and Pearson, 1985)

A TADF will be higher than the corresponding DADF when the animal slows down upon encountering a heavier load since the dynamometer will spend more of its time measuring the heavy load. The opposite will apply when the animal slows down while pulling a lighter load, for example, when turning round at the end of a furrow. Either situation will produce errors (Lawrence and Pearson, 1985).

DADF should therefore be used when comparing the work inputs required for different draught animal operations, or when calculating energy/food requirements for the performance of specific tasks.

Over the past eight years at least two instruments have been developed for the measurement of draught animal performance in the field. The ergometer developed at the CTVM (Lawrence and Pearson, 1985) was designed specifically for measuring the distance travelled, work output and draught force of single or paired draught animals. The ergometer consisted of two parts: 1) an odometer; and 2) an integrate and display (ID) unit. In addition the system required an electronic load cell, which was capable of operating over an appropriate range of draught forces.

O'Neill, Hayton and Sims (1989) constructed 'the AFRC-Engineering draught animal performance data-logger'. The apparatus modified and recorded three mechanical (draught force, angle of application of draught force, speed) and four physiological (heart rate, respiration rate, body temperature, stepping rate) variables. Signals from the sensors attached to the animal and the implement were conditioned electronically and then logged into a programmable recorder. The apparatus has since been developed to include the measurement of O_2 consumption (Howell and O'Neill, 1990).

2.9 MEASUREMENTS OF THE ENERGY REQUIREMENTS OF RUMINANT DRAUGHT ANIMALS

The advent of modern methods of gas analysis made it possible to take measurements from working animals wearing 'leaky' face masks (Section 2.4). The activities that working animals perform can be divided into walking, carrying loads, pulling loads and raising the animal's own weight when walking. Hall and Brody (1934) were the first workers to report on the energy cost of walking on a treadmill in cattle. The few systematic studies carried out on ruminant draught animals have been summarised in Table 3.

TABLE 3

Published values for energy expenditure for walking and working in draught ruminant animals and for the efficiency of doing work.

Activity	Energy Expenditure Average Value	Animal(s)	Authors
	1.9	Cattle (*Bos taurus*)	Brody (1945)
For walking	2.0	Cattle (*Bos taurus*)	Ribeiro *et al* (1977)
(J/m per kg	0.5 - 2.8	Cattle (*Bos indicus*)	King (1981)
live weight)	2.0	Cattle	ARC (1980)
	2.1	Brahman cattle/ buffaloes	Lawrence and Stibbards (1990)
Carrying loads (J/m per kg carried)	2.6	Brahman cattle	Lawrence and Stibbards (1990)
	4.2	Water buffalo	
Efficiency[1] of doing work pulling loads (work done/ energy used)	0.30	Brahman cattle	Lawrence and Stibbards (1990)
	0.37	Buffaloes	
Efficiency of doing work raising body weight (work done/ energy used)	0.36	Brahman cattle and Brahman x Friesian cattle	Thomas and Pearson (1986)
	0.35	Cattle	ARC (1980)

1 Efficiency is the ratio of output to input expressed as a fraction or a percentage.

The values from Table 3 have subsequently been used in factorial estimates of the net energy (NE) expenditure of animals working in the field (Lawrence, 1985; 1987a; Mathers, 1984; Mathers, Pearson, Sneddon, Matthewman and Smith, 1985). This system was an extension of the metabolisable energy (ME) system put forward by the ARC (1980). The necessary information to make estimates of the NE used for work can be described as:

energy for walking
+ energy for carrying loads
+ energy for pulling loads
+ energy for walking uphill

Or in formula:

$$E = AFM + BFL + W/C + 9.81HM/D \qquad \text{(eq. 4)}$$

where
E = extra energy used for work (kJ)
F = distance travelled (km)
M = liveweight (kg)
L = load carried (kg)
W = work done whilst pulling loads (kJ)
H = distance moved vertically upwards (km)
A = energy used to move 1 kg of body weight 1 m horizontally (J)
B = energy used to move 1 kg of applied load 1 m horizontally (J)
C = efficiency of doing mechanical work (work done / energy used)
D = efficiency of raising body weight (work done raising body rate / energy used)

Factors M, L, and H could all be determined with relative ease and F and W can be measured using equipment such as the CTVM ergometer (Section 2.8). Establishment of A, B, C, and D was still restricted to measurements in the simple and simulated surroundings of the laboratory.

Lawrence (1985) considered that maintenance ME requirements could be assumed to be the same as for non-working animals and that ME is used with the same efficiency for both maintenance and work. This argument was based on the assertion that the heat increment associated with work is the same as for maintenance, since in both cases it is produced mainly as a result of converting the ME in the diet to the correct form for fuelling the muscle tissue, be it at a higher rate than in the non-working animal. This argument is not strictly true, since during exercise there is a pronounced shift in the metabolites, from acetate to long chained fatty acids, used to fuel the muscle tissue (Bird, Chandler and Bell, 1981; Pethick, 1984; Preston and Leng, 1987), which could influence the efficiency of use of ME. Standing metabolic rate on working days showed a pronounced increase (26%) over and above the resting metabolism (Lawrence, Sosa and Campbell, 1989). This has obviously important implications when calculations of the total energy expenditure are made. Further work by Lawrence, Buck and Campbell (1989), indicated that animals fed below maintenance showed a significant increase in resting metabolic rate for up to 16 h after work as compared to resting metabolic rate on non-working days. In well-fed animals no such increase was measured. The explanation given for this phenomenon was that animals were resynthesising the reserves used during work. On the described diet, however, there would have been no metabolites available to restore body reserves and it was more likely that body reserves were redistributed since the animals were in a good condition at the start of the experiment. Nevertheless, the observation was an important one and further investigation including the effect of body condition on this phenomenon is required.

Martin and Teleni (1989) suggested that the greater reliance of untrained animals on anaerobic metabolism rendered them less efficient users of ME than trained animals. Work carried out by Teleni and Pieterson (1989) showed that this reduction in efficiency amounted to approximately 6%.

An adaptive trait to hot environments is to reduce the thyroxine output, which in turn reduces metabolic rate. It could be hypothesised that *Bos indicus* cattle have a lower metabolic rate *per se*. Work by Frish and Vercoe (1969, 1976 and 1977) and Vercoe (1970a,b) supported this hypothesis, whereas work carried out by Kibler and Brody (1951, 1954) and Blaxter, Clapperton and Wainman (1966) was less conclusive.

All these results plus the influence of the position of saddles (Lawrence and Stibbards, 1990), walking in mud (Lawrence, 1987b) and the influence of negative gradients (Dijkman, 1992) on energy consumption further emphasised the careful consideration that has to be given when calculations of energy consumption, using a factorial method, are carried out. At present, however, the factorial method is the only practical technique to estimate the energy requirements of draught animals in the field over extended periods.

2.10 CONCLUSIONS FROM THE LITERATURE REVIEW

Although the technology for use in indirect calorimetry measurements has progressed substantially over the past 50 years, only a few suitable instruments for use with draught animals in the field have been developed. The DLW method (Section 2.6.2) has a great potential application in the medium term measurement of energy expenditure by ruminant draught animals. Financial restrictions however, make it unlikely that this method will become available in the near future.

Portable breath analysis appears, at present, to be the only feasible option for the measurement of energy expenditure in the field.

The modification and validation of the Oxylog, started in 1987, proved to have a number of advantages over the other portable breath techniques described in Section 2.5.2.

The Oxylog had a proven track record, it analysed expired and inspired air directly and hence did not need a laboratory or a large and complicated support network and moreover it was relatively cheap compared to the other techniques discussed in Section 2.5.2. Research described in Section 2.9 on the influence of the terrain, environment and management practices on the energy expenditure for the different tasks that animals perform in the field, emphasise the importance of measuring energy expenditure during the day to day working routine.

It was therefore felt that the further development of this very promising method for use in ruminant draught animals was warranted.

2.11 OBJECTIVES OF THE THESIS

The aim of the work described here was first to adapt and test the Oxylog to overcome the problems encountered with the facemask design. Secondly the aim was to test the influence of load and various soil conditions on the energy expenditure of draught animals for these different activities. This was done by carrying out measurements on buffaloes pulling carts in an oil-palm plantation in Colombia and in Nigeria with Bunaji bulls working on different soil types.

CHAPTER THREE
INSTRUMENTATION USED IN THE EXPERIMENTS

3.1 INTRODUCTION

This Chapter briefly explains the various instruments used in the course of the three experiments. Firstly, the open circuit system used for the Oxylog validation trial (Chapter Four) is described. Secondly, the Oxylog and the ergometer used in the two field studies of energy expenditure of ruminant draught animals (Chapter Five and Six) are detailed.

3.2 THE CTVM OPEN CIRCUIT SYSTEM

This system is illustrated in Figure 6. When the system is in normal use, the animal wears a loose-fitting face-mask through which air is drawn at a constant rate sufficient to collect all the expired air and to keep the CO_2 concentration in the airflow below 1%. The airflow is provided by a multistage centrifugal pump driven by an induction motor (ASEA MT motor-IEC34 PSC) and measured by a mass flowmeter (Hastings, 0 - 1500 l/min). Samples of this mixed expired air are taken continuously by a small sampling pump (Honeybourne Pumps Ltd, 113.015.503.0) and dried by passing through sulphuric acid and a column of magnesium perchlorate and calcium chloride with a silica gel indicator. The samples are then analysed for O_2 decrement, CO_2 and CH_4 concentration.

The concentration of CO_2 in the samples is measured by an infra-red CO_2 analyser (Servomex I.R.P.A. 404) and the CH_4 concentration by an infra-red CH_4 analyser (Servomex I.R.P.A. 404). These apparatus measure the

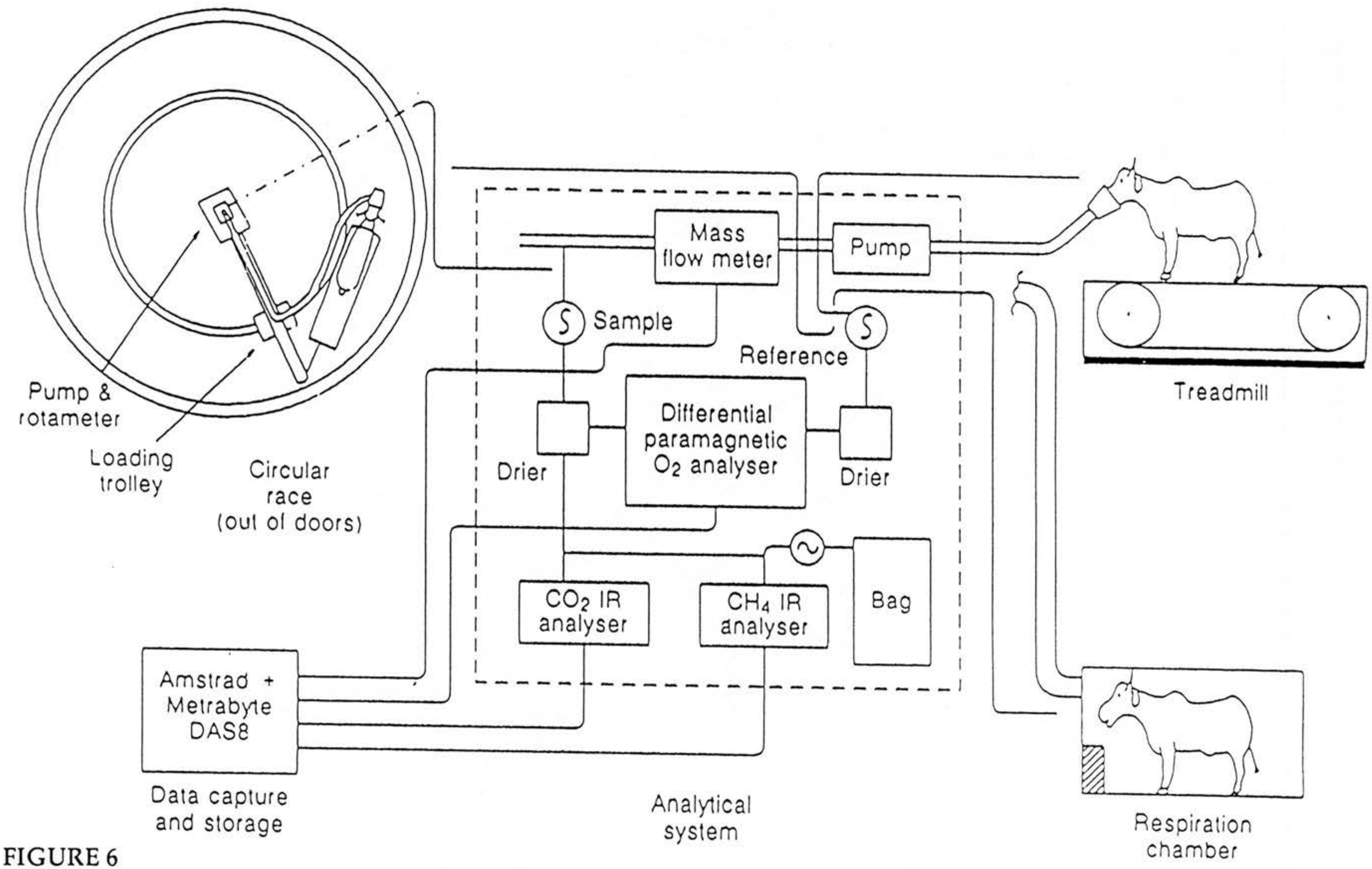


FIGURE 6

Classic 'open circuit' gas analysis system at the CTVM, for use with large draught animals at rest or during work.

(Lawrence and Pearson,1989)

concentration by changing the vibrational or rotational energy of the molecules present, and subsequent recording of the amount of electromagnetic radiation absorbed by the sample in the wave band characteristic for CO_2 or CH_4.

Part of the sample is channelled through a para-magnetic O_2 analyser (Taylor Servomex O.A. 184), which measures the partial pressure of O_2 using the sensitivity of O_2 in a magnetic field. At the same time atmospheric air is drawn into the reference channel and analysed. This allows the percentage difference in O_2 between inspired and expired air to be calculated. The outputs of the three gas analysers are amplified and sampled at 5 Hz by a modified personal computer. Values are averaged at suitable intervals and stored for subsequent calculation.

3.3 THE OXYLOG

The dimensions of the Oxylog are 18 x 8 x 22 cm with a weight of approximately 2.6 kg. Digital light-emitting diodes (LED) displays give readings of cumulative O_2 consumption (l) (9999.9 l, resolution 0.1 l), O_2 consumption per minute (l), ventilation volume (l) per minute and cumulative ventilation volume (l) (99999 l, resolution one l). The power for the Oxylog is provided by rechargeable batteries which allow 12 h continuous use and a recorder output is provided (Plate 2).

The Oxylog calculates the volume of O_2 consumed using the following formula:

$$VO_2 = \frac{(PO_2\text{insp.} - PO_2\text{exp.})\ V\ \text{insp.air}}{760}$$

where VO_2 = volume of O_2 consumed (l)
PO_2insp. = partial pressure of O_2 in inspired air (mm Hg)
PO_2exp. = partial pressure of O_2 in expired air (mm Hg)
V insp.air = volume of inspired air (l)
760 = standard pressure (mm Hg)

PLATE 2

The Oxylog analysis and recording unit.

The volume of O_2 calculated by this formula is only correct when the RQ equals 1, and variations in RQ introduce errors from -5.3% when RQ = 0.7, to +1.8% when RQ = 1.1 (Harrison *et al*, 1982). These errors can be minimised if the volume of O_2 displayed on the Oxylog is used to calculate energy expenditure.

When the O_2 consumption is calculated using the inspired air volume, the use of a constant calorific factor per l of O_2 consumed to estimate the energy expenditure, gives a lower percentage difference with the actual energy expenditure, when RQ is smaller than 1 than when the expired volume was used to calculate the O_2 consumption (Weir, 1949) (Table 4).

TABLE 4

Energy expenditure calculation using the Oxylog

actual O_2 consumption	= 4 l
RQ	= 0.7
actual CO_2 prod.	= 4 x 0.7 = 2.8 l
inlet volume	= 100 l
outlet volume	= 100 - 4 + 2.8 = 98.8 l
inlet conc. O_2	= 21%
outlet conc. O_2	= 17 x 100 / 98.8 = 17.21%

actual heat production using equation 1:

$$4 \times 16.16 + 2.8 \times 5.09 = 78.9 \text{ kJ}$$

calculation of heat production using equation 3:
calculated by inlet volume (Oxylog):

$$((21 - 17.21) \times 100) \times 20.7 = 78.45 \text{ kJ}$$

calculation of heat production using equation 3:
calculated by outlet volume:

$$((21 - 17.21) \times 98.8) \times 20.7 = 77.5 \text{ kJ}$$

With RQ values larger than 1, calculation of the O_2 consumption using the expired volume would give a better estimate for the heat production.

In well-fed draught animals the RQ normally varies between 0.7 and 1 (Figure 1) and the calculations made by the Oxylog would give a lower per-

In well-fed draught animals the RQ normally varies between 0.7 and 1 (Figure 1) and the calculations made by the Oxylog would give a lower percentage error in the estimate of heat production.

The first stages of the modification of the Oxylog for use with oxen were previously described by Dijkman (1989). Rather than the development of a new portable O_2 consumption meter, it was decided to modify the Oxylog, which had a proven track record (Harrison *et al*, 1982).

3.3.1 Adaptations made to the Oxylog

The Oxylog was specially designed for measurement of O_2 consumption in humans, and the flowmeter and valves had to be newly manufactured to cope with the larger ventilation volumes to enable measurement in draught animals. These adaptations are described in detail by Dijkman (1989). Briefly, it was found possible to make scaled-up versions of the turbine flowmeter, which gave good linear responses when calibrated using a reciprocating pump operated at different speeds to give a range of flow rates. The capacity of the inlet and outlet valves was increased simply by increasing their number from 1 to 3 and placing them in larger tubes. The tube connecting the mask to the Oxylog was fitted with a by-pass so that only a fraction of the expired air passed the sampling pump (Figure 7).

Results of the first validation experiments were encouraging, though the Oxylog tended to underestimate the real O_2 consumption, as measured by the open circuit system, by approximately 7%. These results were largely attributed to the design of the mask, which had problems with the airtight sealing around the animal's face. The mask used in these first trials had the further disadvantages of fitting one animal only and the airtight sealing (cling film coated rubber foam) was time consuming to make and wore out quickly.

FIGURE 7

The Oxylog with the tube connected to the mask with the fitted by-pass.

A: Sample by-pass B: Oxylog signal processing unit

3.4 THE CTVM ERGOMETER

The ergometer developed at the CTVM (Lawrence and Pearson, 1985) was designed specifically for measuring the distance travelled, work output and draught force of single or paired draught animals. The ergometer consists of two parts: 1) an odometer; and 2) an integrate and display (ID) unit. In addition the system requires an electronic load cell which has an input of 10 V, an output of 0 - 20 mV and which is capable of operating over an appropriate range of draught forces (e.g. 0 - 3000 N).

The odometer consists of:

(a) A shaft coupled to a cross piece via a universal joint.

(b) A pair of forks to support parts (c) and (d). The forks may be rotated in relation to part (a) so the odometer may be attached to vertical or horizontal parts of the implement.

(c) A rear bicycle wheel fitted with a 60-tooth timing pulley. The pulley screws onto the wheel in place of the back sprocket or gear block.

(d) The distance detector. This consists of a flat sealed aluminium disk, containing a wheel with 60 slots round the perimeter which passes through an infra-red detector. The gearing system is such that 360 slots pass through the detector per revolution of the bicycle wheel. The ID unit provides the power for the circuits in the load cell and the odometer and processes the signals from them. It may be used in several modes:

(i) Calibration mode. A known weight (typically 100 kg) is suspended from the load cell, the amplified signal from the load cell is fed to the analogue to digital convertor which is then pulsed by the internal oscillator circuit 1024 times at a rate of 400 Hz every alternate 2.56 s. If the odometer is fitted with a 26 inch wheel, then this number of pulses with a load of 100 kg would be equivalent to 100 x 9.81 x 0.0058 x 1024 = 5826 J of mechanical work. If this number is divided by the reading on the work counter then the result gives the number of J of work equivalent to one count.

(ii) Work and draught force mode. The ID unit is switched to receive pulses from the odometer while the animal is pulling a load via the load cell. In this mode the lower display records the total number of pulses which are equivalent to the distance travelled. The upper display shows the result of rapid and continuous integration of the amplified output of the load cell with respect to distance, i.e. the work done by the oxen. Both displays are cumulative and may be divided by factors up to 256. Accurate measurement of work done and distance travelled can thus be made over distances from 5 m to 30 km. Division of the work done by the distance travelled gives a measure of the true draught force (DADF).

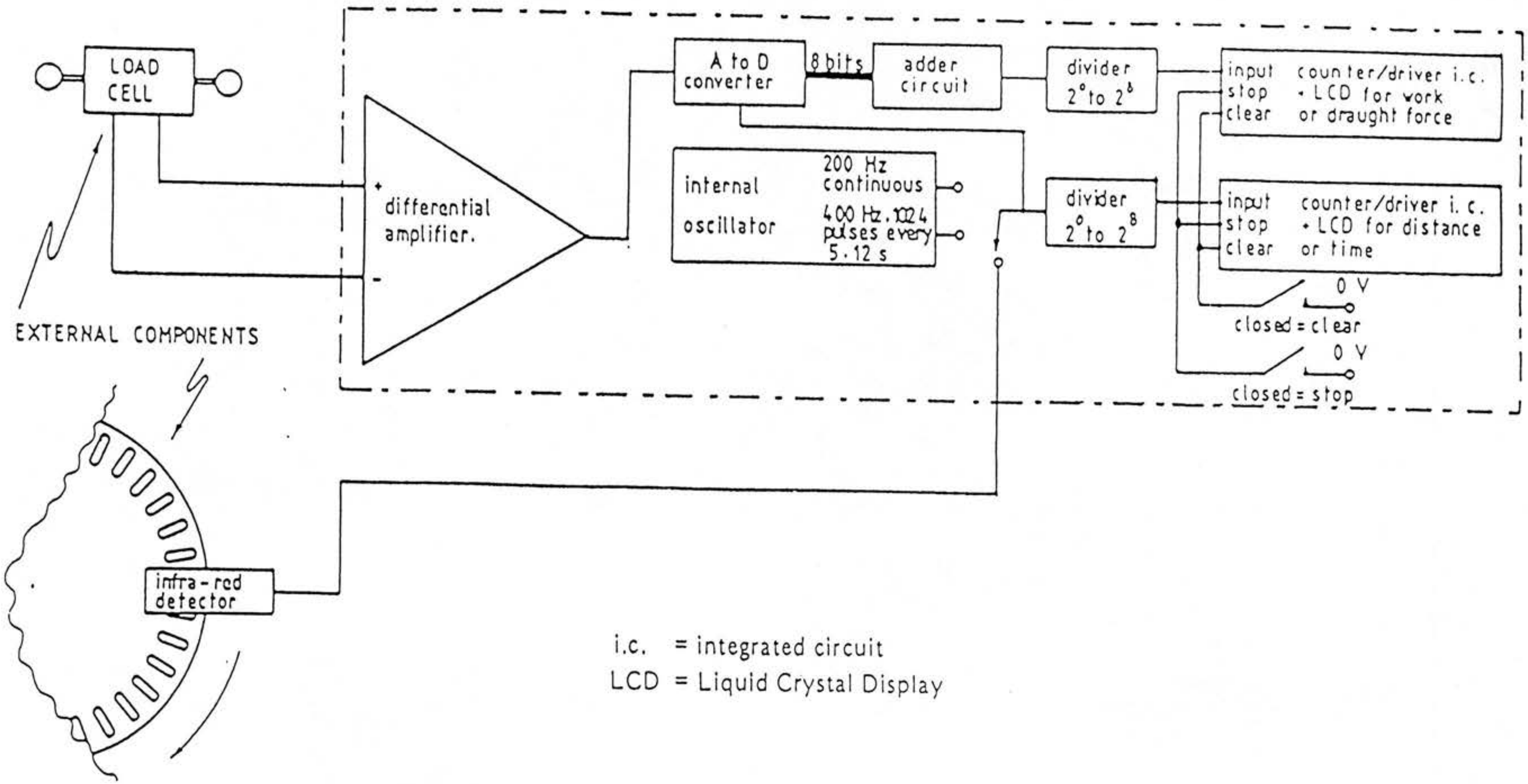
(iii) When the animal is pulling a load via the load cell and the ID unit receives pulses from the oscillator as in section (a), time averages of draught force may be made repeatedly for periods of 2.56 s, or continuously at an oscillator rate of 200 Hz. Used in this mode the ID unit acts like a normal dynamometer. However, for reasons explained in Section 2.8, this method is not recommended for use with draught animals. This mode may, however, find use as a means of weighing objects up to the limit of the load cell (Figure 8).

3.4.1 Elapsed working time (EWT) unit

This unit is a separate standard digital clock with stop-watch, standard and dual time modes, which can be plugged into the main ID unit. In the dual time mode, the clock records the time the animal spends walking faster than a minimum speed, which is set at 0.2 m/s when the odometer is fitted with a 26 inch wheel.

More specific information about the CTVM ergometer and the EWT unit can be found in the CTVM ergometer instruction manual (CTVM, 1987).

There is now a new version of the ergometer which measures directly in kJ, m and s of EWT. It can also be used to give direct repeat measurements of DADF and speed over 4 m distances (P.R. Lawrence, personal communication).



i.c. = integrated circuit
LCD = Liquid Crystal Display

FIGURE 8

Design of the CTVM ergometer circuits and the external components.

(Lawrence and Pearson, 1985)

CHAPTER FOUR
FACEMASK DESIGN AND VALIDATION

4.1 INTRODUCTION

The first validation trails with the modified Oxylog (Dijkman, 1989), whilst relatively successful, stressed the need for a different approach to the design and manufacture of the facemask. The facemask had failed on a number of points: ease of manufacture, airtightness and the fact that each animal would need a separate mask. The present validation trial was set up to validate a new mask design. In the months preceding the validation trial, a large number of different materials and shapes were considered for the facemask. It was finally decided to use a basic frame made from 10 mm plywood of a geometrically simple shape. The airtight seal was made from 0.5 mm thick natural latex rubber. This meant that one mask would fit a variety of animals and new masks to fit animals of different sizes could be made quickly, easily and cheaply.

This Chapter describes the design, the manufacture and the validation of this facemask and the modified Oxylog.

4.2 MATERIALS AND METHODS

4.2.1 Animal and training

The validation experiment was carried out with Josey, a Brahman cow, aged 7.5 years, liveweight 425 kg. She had been used in the first validation trial and was thus thoroughly familiar with the experimental procedures. Because these measurements were made using a new facemask while exercising on a treadmill, rather than in the circular race as in the previous Oxylog validation trial (Dijkman, 1989), Josey was trained to the mask, over a period of three weeks, whilst walking at different speeds on the treadmill.

4.2.2 Gas analysis equipment

The modified Oxylog and the exercise and gas analysis system at the CTVM (Chapter Three) were used in the experiment. Minor modifications were made to the gas analysis system, to enable simultaneous measurements to be made whilst using the Oxylog.

4.2.3 Treadmill

The measurements were made whilst Josey exercised on a treadmill. The velocity of the treadmill belt was regulated with a variable speed, direct current motor.

To obtain different levels of O_2 consumption, the animal was exercised over a range of speeds (0.6 to 1.3 m/s) and observed during resting periods.

4.2.4 Open circuit system

During normal use, the animal wears a loose-fitting facemask through which air is drawn at a constant rate sufficient to collect all the expired air and to keep the CO_2 concentration in the airflow below 1%. In this experiment however, the animal was fitted with an airtight facemask and breathed in and out through valves. On the inlet side the inhaled air passed through the turbine flowmeter of the Oxylog. The exhaled air was ducted to a wooden box which contained the Oxylog. The box was attached to the animal's yoke, and was fitted with a permeable foam-rubber top. Inside the box the expired air stream was split in two by means of a 'T' piece so that a sample could be passed through the Oxylog. The outlet from the box was connected to the open circuit system in the position normally occupied by the loose-fitting facemask (Figure 9). In this way all the expired air, both that which had been

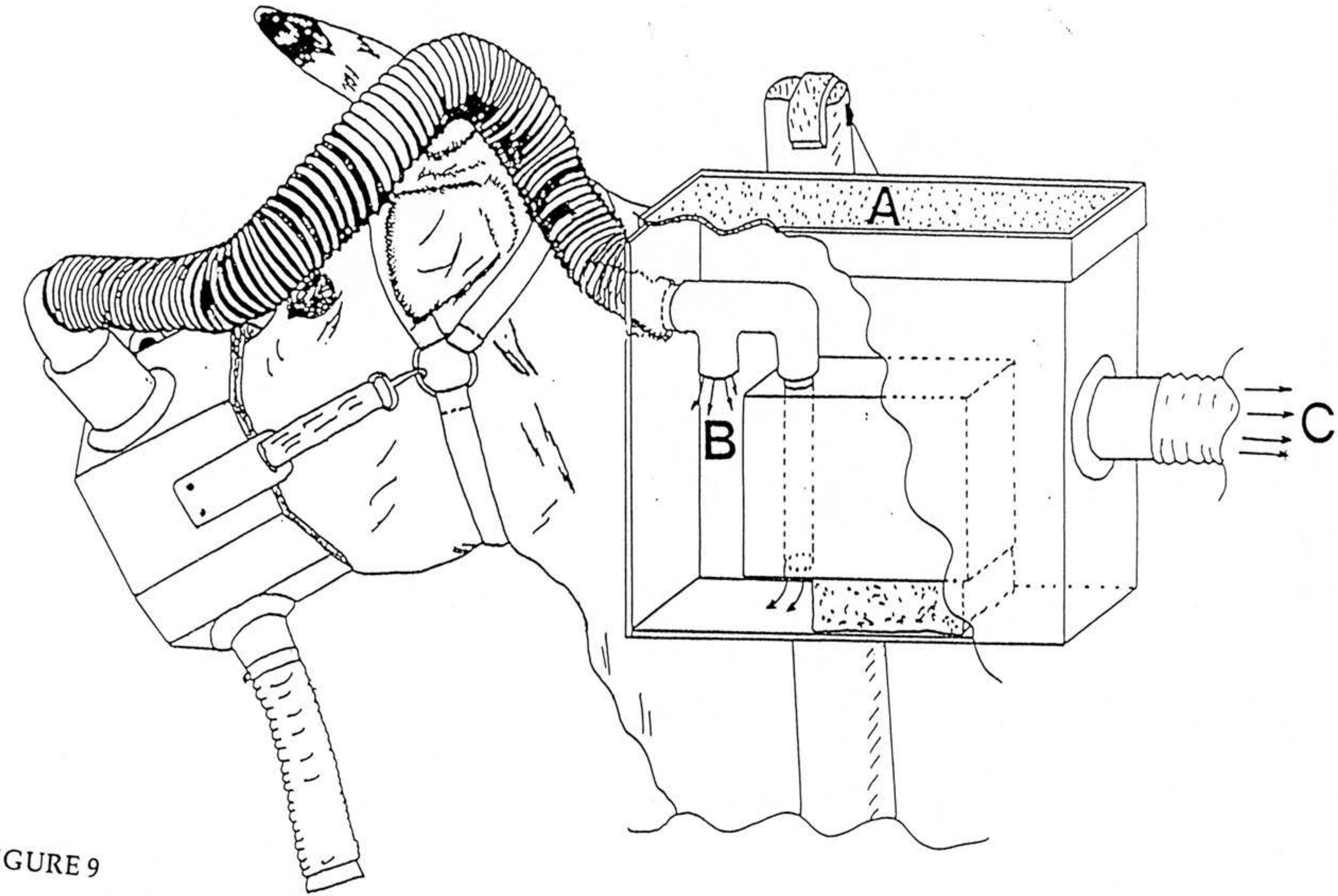


FIGURE 9

Diagram of the experimental system and validation set-up of the Oxylog with the open circuit system.

A: Permeable foam-rubber top

B: T-piece, splitting the expired air stream

C: Outlet to the open circuit system collecting all the through the Oxylog and that which had by-passed it, was drawn through the open circuit system.

4.2.5 Facemask design and manufacture

The outer shell of the facemask was made from 10 mm good quality plywood. The mask was built from seven pieces which were glued together, its size determined by the width and height of the animal's muzzle (Appendix 1). Suitable holes were made in the outer shell of the mask where the inhalation, exhalation and spit trap components could be fitted. The wooden structure was subsequently painted with 'Hammerite' metal finish paint, which sealed the wood and made it water repellent. An annular cuff was made from 0.5 mm thick black natural rubber 'grade s' (Four D-rubber Co. Ltd., Derbyshire, U.K.), which sealed perfectly at a point just behind the animal's nose when the mask was pushed onto the face. The front of the mask was covered with 1 mm thick black natural rubber 'grade s', which also fitted airtight around an aluminium alloy rod connected to the nose ring to enable easy handling of the animal (Plate 3). The rubber cuffs were glued with a special latex glue 'Bostik 3851' (General Engineering Supply Co., London, U.K.) which welds the layers of rubber together. The rubber cuffs were thereafter secured in position using electrical tape on the outer surface of the mask.

A step-by-step guide to the manufacture of the facemask is given in Appendix 1.

4.2.6 Mass flowmeter calibration

The calibration of the Rotameter was described in detail by Dijkman (1989) and the mass flowmeter was calibrated using the same principle. Briefly, a known quantity of CO_2, which was determined gravimetrically, was released into the tubing leading to the mass flowmeter. To prevent depen-

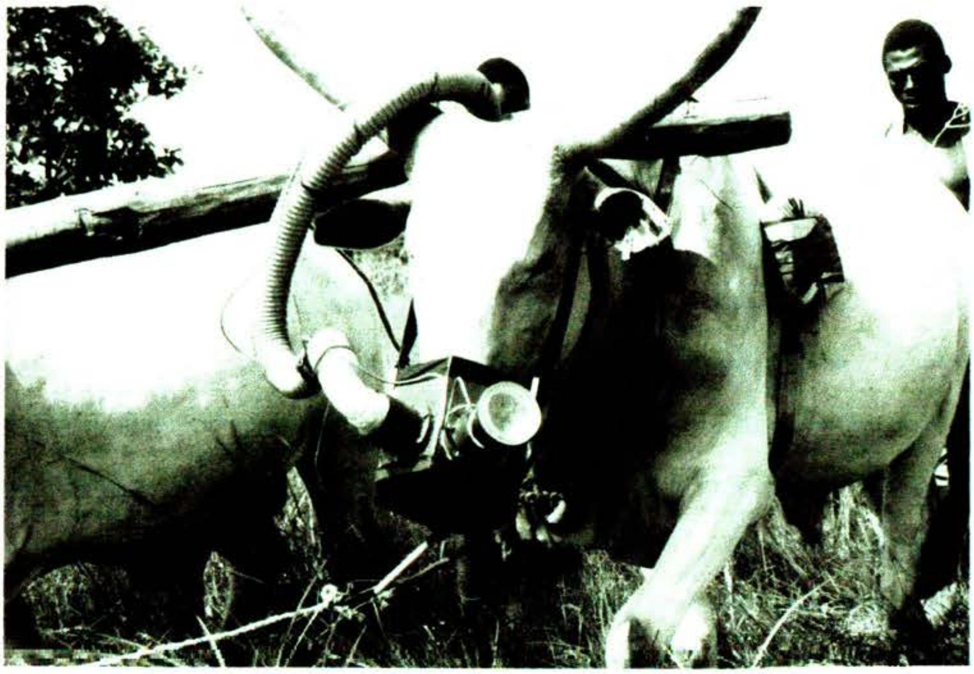


PLATE 3

The aluminium alloy rod connected to the nose ring of a Bunaji bull in Nigeria, with the Oxylog facemask in place.

dency on the linearity of the CO_2 analyser, the flow from the cylinder was set to give a concentration similar to the concentration of the span gas used for the calibration of the analyser. The values recorded by the computer, were stored on a floppy disk and analysed with the use of a spreadsheet. The correction factor for the indicated flowrate by the mass flowmeter was subsequently calculated by dividing the actual weight of CO_2 released by the measured weight. The actual rate of flow was: STP corrected measured flow x 0.68.

4.2.7 Calibration of the gas analysis equipment

The three analysers were switched on 1 week before the actual experimental determinations began. Calibration procedures described below were carried out every day before the start of the measurements.

4.2.7.1 *CO_2 analyser*

The CO_2 analyser is zero-calibrated using a reference gas containing 99.99% nitrogen. The span is adjusted using a gas mixture containing 0.891% CO_2 (British Oxygen Company, Special Gases, London).

4.2.7.2 *CH_4 analyser*

The CH_4 analyser is set to zero using the same reference gas used for the CO_2 analyser. The span is adjusted using a gas mixture containing 0.01% CH_4 (British Oxygen Company, Special Gases, London).

4.2.7.3 *O_2 analyser*

The reference and sample channel of the O_2 analyser are 'washed out' with atmospheric air by maximising the flowrate through the tubing. After that the flowrate is set to 35 ml/minute and the difference reading on the computer is set to zero.

4.2.8 Experimental period

The length of the separate recording periods were chosen in such a way, that at least 10 readings for O_2 consumption were recorded on the Oxylog, which reduced the possible recording error to 1%. Effectively, this resulted in recording periods lasting from 10.5 to 31 minutes. Total measurement periods lasted from 35 to 97 minutes. To enable comparison of the appropriate recording periods of the Oxylog and the open circuit system, the time needed for samples to reach the gas analysis equipment was established.

Recordings by the gas analysis system were corrected for barometric pressure. Furthermore, CO_2 concentration was corrected for the concentration in the atmospheric air.

Readings from the Oxylog were noted and subsequently calculated by multiplication with the appropriate calibration factors (Dijkman, 1989). Volumes measured by the gas analysis system were calculated by multiplying the average consumption / production per minute (min) by the STP corrected flowrate (mass flowmeter) x correction factor of the mass flowmeter x the length of the period (min). The standard error of the difference (s.e.) between the measurements made by the Oxylog and the open circuit gas analysis system was established, and a paired t-test was carried out on the two sets of data recorded using Minitab statistical software (Ryan, Joiner and Ryan, 1985).

4.3 EXPERIMENTAL RESULTS

The analysed values were obtained in 58 recording periods (Appendix 2). Figure 10 shows the comparison of the volume of O_2 consumed at STP as measured by the gas analysis system (l/min) and the reading on the Oxylog multiplied by the average O_2 consumption at STP per resolution (0.421 l;

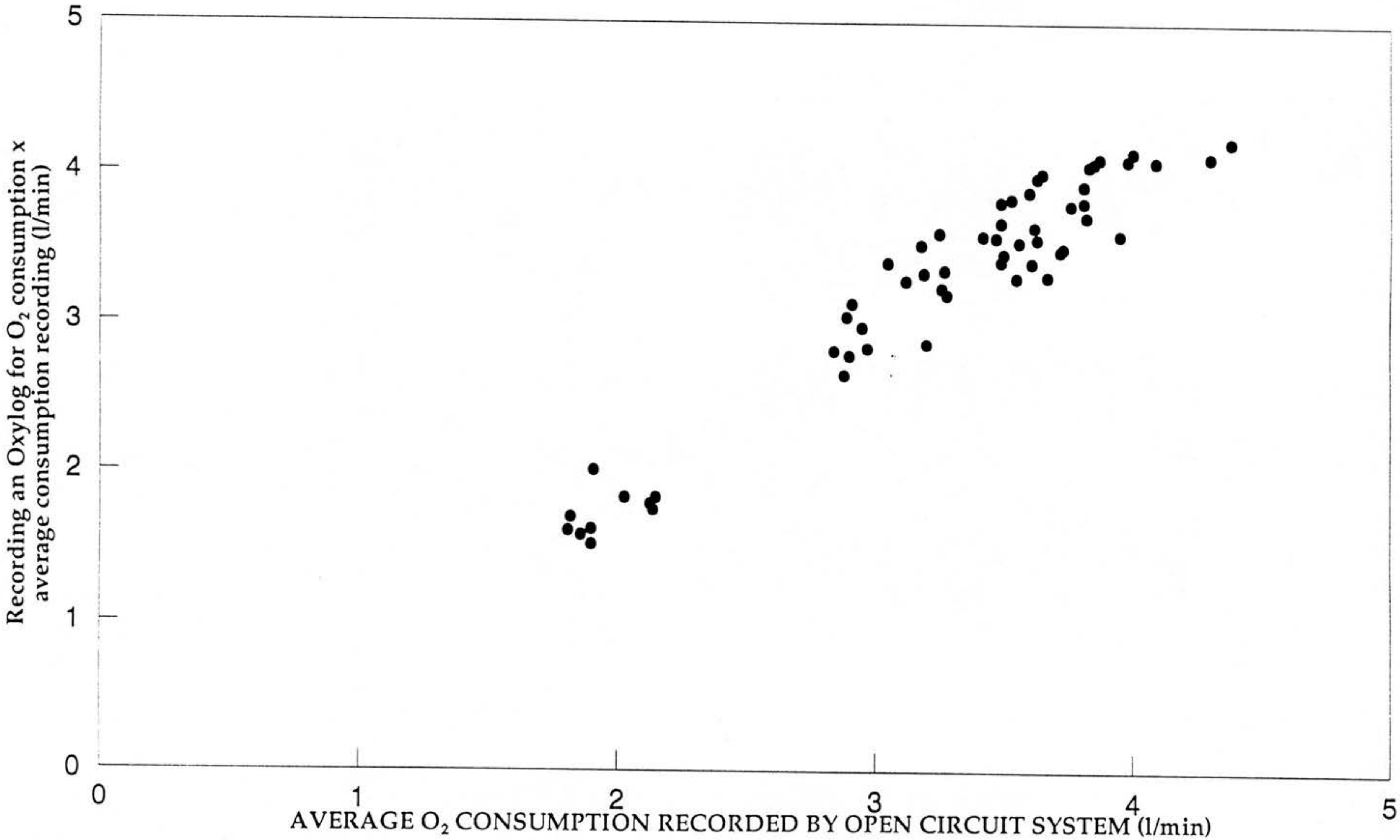


FIGURE 10

Comparison of the O_2 consumption measurements on the open circuit system and the modified Oxylog (l/min).

Dijkman, 1989). This comparison showed that in these separate short recording periods the Oxylog overestimated O_2 consumption on average by 1.2%. The range in the percentage errors however was rather large: -11.5 to +20.6% (s.e. 1.09). A paired t-test of the results however, showed no significant differences between the two observations.

The results of the total measurement periods, when the separate recording periods were pooled (Appendix 2), are shown in Table 5.

TABLE 5

Comparison of measurements (lasting at least 30 minutes) on the open circuit system and the modified Oxylog.

Period	O_2 cons. (1) Open circuit	O_2 cons. (1) Oxylog	% difference
1	293.2	305.7	-4.3
2	285.2	276.3	3.2
3	263.3	250.1	5.0
4	244.9	231.2	5.6
5	223.5	217.9	2.5
6	198.0	192.0	3.0
7	197.3	189.1	4.1
8	194.8	203.7	-4.6
9	194.8	200.7	-3.0
10	177.3	179.7	-1.3
11	153.2	144.8	5.5
12	145.7	138.7	4.8
13	131.5	128.2	2.5
14	83.8	85.4	-1.9

Average difference = 1.51%
s.e. = 0.96

A paired t-test of these results showed no significant difference between the measurements made by the open circuit gas analysis system and the Oxylog. Variation in the percentage error also proved a lot smaller with a range from -4.6 to +5.6% (s.e. 0.96)

4.4 DISCUSSION

The experimental results showed that the measurements made by the open circuit gas analysis system and the Oxylog were in good agreement. Compared to the results from other researchers developing mask techniques for the field measurement of energy expenditure (Horniche *et al*, 1974; Clar, 1991; Zerbini, personal communication), the differences found in the measurements of O_2 made by the open circuit system and the Oxylog were much smaller. Normally technique recording differences of + or - 10% are considered to be appropriate for use in the field (Brockway, 1978). Analysis of the cumulative results indicated that agreement was best, when measurements were taken over longer periods. The Oxylog's response to changes in O_2 concentration is slow compared with the open circuit gas analysis system and by taking longer measurements this was better accounted for.

Inhalation volume as measured by the Oxylog varied between 35 and 130 l/min (Appendix 2), which was well within the calibration limits of the flowmeter (0 - 230 l/min; Dijkman, 1989). Whereas no separate check on the ventilation volume measurements could be made using the described experimental set-up, the results from the comparative measurements of O_2 consumption proved that the flowmeter was reliable and accurate. 'Dead space' in the facemask design is kept to a minimum which prevented excessive rebreathing of expired CO_2 (Clar, 1991).

The facemask design used, proved to be durable and dependable. The design is such that new masks can be manufactured easily and cheaply and it is expected that one size of mask can be used on a variety of animals, with approximately the same size of head. Due to the lack of other available animals, only one animal was used in the validation of the technique, and it was appreciated that this could have had an influence on the experimental results. Masks used by other researchers (Hornicke *et al*, 1974; Clar, 1991) were very expensive and difficult to produce and had the further disadvantage of fitting one animal only.

The latex cuffs are fairly easily tailored, after some practice, and the glue welds the layers of latex together giving a very strong bond. It was found to be advantageous to smear the annular cuff with a lubricant jelly before pushing the mask onto the animal's face. This made the mask easier to push over the muzzle, sealed the annular cuff around the animal's muzzle and prevented skin irritation. Moreover, this mask design was a lot lighter than its predecessor and produced minimal hindrance to Josey, the test animal, during the experimental trials.

Whereas the techniques used in the manufacture of the components are easily learned, a good workshop is needed to do the manufacturing of the various parts. Further problems were encountered with the shelf-life of the latex glue, which lost its adhesive properties quickly, especially under tropical conditions. Although this problem was not solved in the course of the work reported here, it has been solved subsequently by changing to a different latex glue (Autocol, Sifcol, Tunisia).

One of the main disadvantages, even though the method proved to work well technically, remains the fact that animals do not like wearing masks. To ensure that the animals are not distressed or change their breathing pattern, time and patience are needed to get an animal used to the wearing of a facemask.

CHAPTER FIVE
THE ENERGY EXPENDITURE OF RUMINANT DRAUGHT ANIMALS IN A COLOMBIAN OIL-PALM PLANTATION

5.1 INTRODUCTION

The modification and validation of the Oxylog described in Chapter Three, proved that it was possible to measure accurately the O_2 consumption of large ruminants, with this portable instrument. The next step in the validation process was a trial to examine whether the equipment would work satisfactorily in the field. A pilot field trial was carried out in 1990 in Nepal by P.R. Lawrence of which the results were reported by Lawrence *et al* (1991).

One of the few instances where draught animals are utilised on a large scale commercial basis, is in the harvesting of plantation crops. Correspondence with Unilever PLC led to the idea of investigating the energy expenditure of buffaloes (*Bubalus bubalis*) and oxen (*Bos indicus* x *Bos taurus*) working in an oil-palm plantation.

The availability of a large number of draught animals in a relatively small area made the logistics for experimentation very attractive and would facilitate the testing of the Oxylog in a field situation. Moreover, it was an ideal opportunity to obtain more factual information about this type of draught work and the problems related to this specific farming system, as far as draught animal husbandry and health were concerned.

5.2 GENERAL PLANTATION INFORMATION

The Hacienda St. Barbara of Unipalma de los Llanos S.A., Vera Cruz, Meta, Colombia, is one of two oil-palm plantations in Colombia belonging to the Anglo/Dutch conglomerate Unilever. It is located in the western area of the Llanos Orientales at the foothills of the Eastern Cordillera of the Andes (Figure 11).

With mean yearly rainfall of about 2600 mm, mean daily temperature of 28°C and mean total sunshine hours of about 1800 annually, this area of Colombia offers one of the best sites for oil-palm cultivation. Furthermore, the relative proximity to Bogota, the principle market for palm oil in Colombia, ensures rapid delivery of products and parts, both to and from, the plantation.

5.2.1 History

The Hacienda St. Barbara is a relatively new plantation, because initial planting started in 1982. In 1985 first harvesting was carried out and in 1991 the plantation had a total productive area of 1638 hectares. Total harvest of fresh fruit bunches (FFB) in 1990 was 35,916.93 tons, and the prospects were that this would increase further as more hectares were coming into production.

5.2.2 Harvesting

Whereas most oil-palm plantations use tractors in the harvest of the FFB, harvesting in the Hacienda St. Barbara is carried out with both buffaloes and oxen. The system of harvesting employed makes use of one man, plus one buffalo or ox and a cart (Plate 4).

A total of 118 buffaloes and 15 oxen was used to harvest the total productive area. Work periods were from 06.30 h until 12.00 h and from 13.00 h

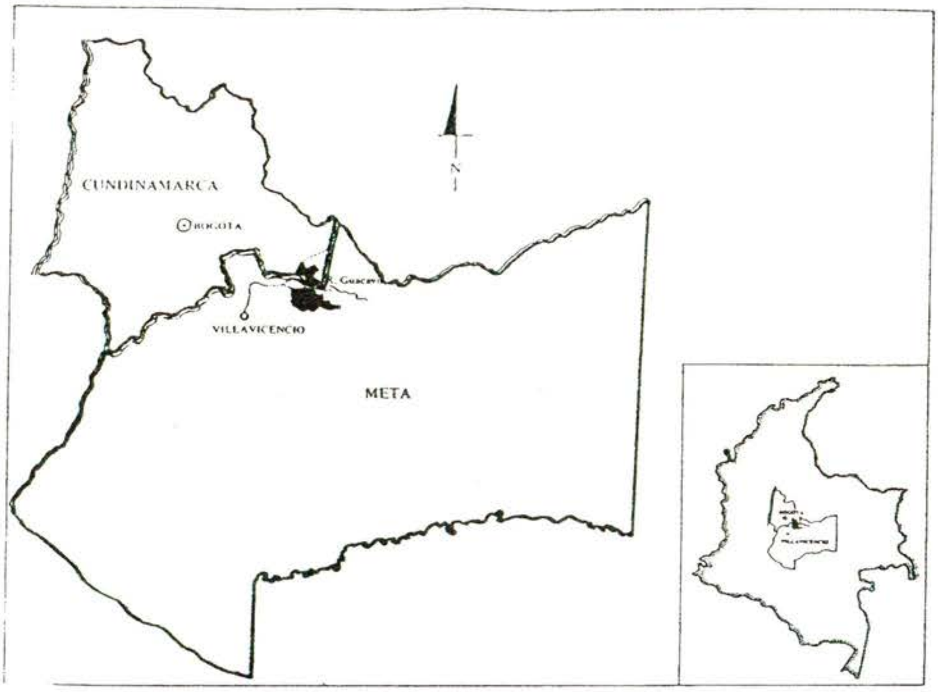


FIGURE 11

Map showing location of the Unipalma oil-palm plantation in the Meta region, corner map shows location within Colombia.

PLATE 4

One man, one buffalo, one cart system of harvesting.

to 15.30 h. Saturday harvesting, once every fortnight, was carried out in the morning from 06.30 h to 12.00 h. A typical harvest per team was 1800 kg of FFB per day. The full nets were dropped near the roadside, where they were collected by a craned truck, which transported the fruits to the extraction plant.

5.2.3 Plantation animals

The plantation owned a total of 142 water buffaloes and 17 crossbred oxen, of these 118 and 15 respectively, were used for harvesting, the rest were either diseased or too young. The castrated male animals are bought when they are 2 - 2.5 years old. When the animals are 3 - 3.5 years old (450 kg), they are trained for a period of approximately six weeks, after which they start work in the plantation. The working animals ranged in weight from 450 to 1000 kg and age ranged between 3.5 - 9 years. On the plantation the animals had *ad libitum* access to the following forages: *Pueraria phaseoloides, Brachiaria decumbens, Panicum maximum,* Palm leaves, *Nepholepsis spp.* and water. Working animals further received 1 kg of molasses during the 1 h lunch break (12.00 - 13.00 h). During this interval the buffaloes also had the chance to wallow.

The carts used weighed approximately 400 kg. The fruits were put into a net, which was placed in the cart hooked on to six connection points on the sides of the cart. Full nets were tied-up and, with the use of the tipping system of the cart (Plate 5), dropped by the road side. Weight per net varied between 600 - 800 kg.

The harvested area per buffalo per day varied between 1 and 3 ha, in the wet and drier periods respectively. During the night, the animals were enclosed in a fenced off area on the plantation. These paddocks, 11 in number and approximately 15 ha in size, were scattered around the plantation in such

PLATE 5

Tipping system of the cart.

PLATE 6

Odometer attachment.

a way that they were never far from the next harvesting place. During the weekends, four enclosures of about 40 ha were used. The parts of the plantation that were used as paddocks were changed every two years.

5.3 MATERIALS AND METHODS

5.3.1 Animals and feeding

Nine animals were used in the experiments: six water buffaloes (*Bubalus bubalis*) and three oxen (*Bos indicus* x *Bos taurus*). All experimental determinations were made at the Hacienda St. Barbara during the months of September 1990 to January 1991. The ages and weights of the animals used are listed in Table 6.

TABLE 6

Details of the animals used during the experiments in a Colombian oil-palm plantation.

Species	Sex	Age (years)	Weight (kg)
1. *Bubalus bubalis*	Castrated male	5.5	625
2. *Bubalus bubalis*	Castrated male	7	805
3. *Bubalus bubalis*	Castrated male	6.5	750
4. *Bubalus bubalis*	Castrated male	6	650
5. *Bubalus bubalis*	Castrated male	7	760
6. *Bubalus bubalis*	Castrated male	7.5	740
7. *Bos i.* x *Bos t.*	Castrated male	6	625
8. *Bos i.* x *Bos t.*	Castrated male	5.5	600
9. *Bos i.* x *Bos t.*	Castrated male	8	700

All animals used in the experimental determinations, had been working in the plantation for over two years. During the experiments animals ate the normal plantation diet. Weekly samples of all available feedstuffs were collected and for each feedstuff were pooled for chemical analysis (Table 7).

Animals were observed on Sundays in the paddocks and time spent eating the different foodstuffs was recorded to estimate the percentage intakes of the available forages. Ambient temperature during the experiments, which were mostly carried out during the morning harvesting, ranged between 25 - 32°C, with a relative humidity ranging between 0.59 and 0.87.

TABLE 7

Analysis of feedstuffs available in the oil-palm plantation (on a dry matter [DM] basis — unless otherwise stated).

Sample	DM g/kgFrM	CP g/kg	GE MJ/kg	Ash g/kg	OM g/kg	NDF g/kg	ADF g/kg
1	226	108	17.7	107	893	719	466
2	238	200	19.5	65	935	620	494
3	317	97	18.1	120	913	767	496
4	289	100	17.7	92	908	712	527
5	172	134	18.2	134	866	526	429
6	440	106	18.6	120	880	612	545
7	761	30	20.5	86	737	—	—

N.B. Figures for each feedstuff are the result of analysis of a pooled sample of 18 weeks.

FrM = Fresh matter
CP = Crude protein
GE = Gross energy
OM = Organic matter
NDF = Neutral detergent fibre
ADF = Acid detergent fibre

1 : *Brachiaria decumbens*
2 : *Pueraria phaseoloides*
3 : *Panicum maximum*
4 : *Cyperus Luzulae*
5 : *Nepholepsis spp.*
6 : Palm leaves
7 : Cane Molasses

5.3.2 Instrumentation

An ergometer (Section 3.4) was used to measure and record the distance travelled (m) and the work done (J) by the animals. The odometer wheel, with the infra-red detector, was attached at the back of the cart with the use of a screwed on iron adaptor. The universal joint at the end of the shaft was tied on to this adaptor with a rubber strip (Plate 6).

Initial problems were encountered with the placing of the load cell (Type 241 by Novatech Ltd, Hastings, England, 0 - 3000 N), to measure the force exerted by the animals. The solution was found by connecting the animal via the load cell to the cart with two leads tied to the collar and a swingle tree (Plate 7). The analysing and recording unit of the Oxylog was placed on the left hand shaft of the cart (Plate 8). Distance and force were monitored continuously throughout the working day by the ergometer. O_2 consumption however was measured for 1 to 3 h per day only. The wearing of the Oxylog face mask prevents the animal from eating and drinking and it was thought that longer measurement periods could upset the animals. Readings from the instruments were recorded every half hour.

During the morning harvesting, typically two full nets were achieved. During the afternoon harvesting, typically one net was filled. The actual work output of the animals was highly variable from day to day: it was for example dependent on the weather conditions, the soil conditions, the availability of fruits in the part of the plantation harvested and the worker (Appendix 3). Nevertheless, because the buffaloes always follow the same two weekly route and the weather conditions were more or less consistent during the greatest part of the year, it was considered possible to determine an average weekly workload. Moreover, the actual variation proved to be smaller than expected with the marked differences occurring when large distances had to be covered to reach the next harvesting place during the working day.

The nine animals used in the experiment were all monitored over four full working days (Appendix 3). All measurements were taken while the animals were following the normal plantation working routine. The complete experimental set up is shown in Plate 9.

PLATE 7

The load cell connection to the cart.

PLATE 8

The placement of the Oxylog analysing and recording unit on the cart.

PLATE 9

The complete experimental set up.

5.3.3 Establishment of the daily work output and comparison of the efficiency of buffaloes and oxen

It was anticipated, because the animals normally work with one person only, that the presence of more people could upset them. Hence, one or two days were used to familiarise each animal with the presence of different people. During these days both the distance and the work done were measured continuously, as these apparatus are connected to cart and harness without any physical contact with the animal.

After this period the mask was fitted on the animal. Fifty % of the animals tried with the mask refused to wear it. However, the nine animals that did accept it did not show major signs of distress and the breathing pattern observed before the fitting of the mask remained, in most cases, unchanged. Moreover, it was observed that during some resting periods the animals were ruminating while wearing the mask. In the results only the data obtained from the nine animals which accepted the mask have been reported.

Standing metabolic rate (SMR) was calculated as the average minute (60 s) O_2 consumption during resting periods lasting longer than 15 minutes. The mask periods were chosen in such a way that they represented the whole range of workloads (cart from empty to full).

The energy cost of doing work was defined as an efficiency factor where: efficiency = work done/[energy expended when loaded — energy expended to walk the same distance at the same speed but unloaded].

To enable the calculation of the efficiency of work done, at the start of every mask period the readings on the ergometer for work done and distance travelled were recorded. Calculation of the energy expenditure during the 'mask' periods was done by multiplying the O_2 consumption by 20.7 kJ (eq. 3).

The energy cost of walking was defined as 2.1 J/m/kg (Lawrence and Stibbards, 1990).

EWT was defined as 'when moving at a speed greater then 0.2 m/s' (Lawrence and Pearson, 1985).

The results of the Oxylog measurements for the extra energy used during work (= Total energy - SMR) were further compared with the results of the calculation of the energy expenditure using a factorial method (Lawrence, 1985; eq. 4). The results of the Oxylog measurements for SMR were compared with the calculated ME maintenance requirements: 0.58 MJ/kgW$^{0.73}$ (Ministry of Agriculture, Fisheries and Food [MAFF], 1984; when W = body weight in kg), although it was appreciated that SMR as measured here is not strictly comparable with ME, which is a 24 h average. Statistical analysis was carried out using Minitab statistical software (Ryan *et al*, 1985).

Other factors monitored during the experimental period were draught animal health and temperament.

5.4 EXPERIMENTAL RESULTS

5.4.1 O_2 consumption

The O_2 consumption, as measured by the Oxylog, during resting periods longer than 15 minutes for all experimental animals ranged from 0.013 to 0.020 l/min/kg$^{0.73}$ with an average of 0.016 l/min/kg$^{0.73}$ (number of observations [n] = 36, s.e. 0.0003).

Average O_2 consumption during the mask periods was 0.025 l/min/kg$^{0.73}$ (n = 36, s.e. 0.0008), with a range of 0.016 to 0.034 l/min/kg$^{0.73}$.

5.4.2 Ventilation volume

The ventilation volume, as measured by the Oxylog, during resting periods which were longer than 15 minutes for all experimental animals varied between 0.53 and 0.95 l/min/kg$^{0.73}$, with an average of 0.73 l/min/kg$^{0.73}$ (n = 36, s.e. 0.018). Average ventilation volume during the mask periods was 1.20 l/min/kg$^{0.73}$ (n = 36, s.e. 0.025), with a range of 0.83 to 1.46 l/min/kg$^{0.73}$ (Appendix 4).

5.4.3 Total work done, distance walked and EWT

Work done, as measured by the ergometer, during the harvesting periods for all experimental animals ranged from 0.2 to 1.4 MJ/day, with an average of 0.625 MJ/day (n = 36, s.e. 0.05).

Distance travelled ranged from 595 to 3404 m/day, with an average of 1867 m/day (n = 36, s.e. 133). Walking speed ranged from 0.46 to 1.1 m/s, with an average of 0.76 m/s (n = 33, s.e. 0.027).

EWT, as measured by the EWT unit, during the harvesting periods averaged 39.7 min (n = 33, s.e. 2.74), with a range of 18 to 73 min. This means that animals on average spent 9% only of the total harvesting period working (Appendix 3).

5.4.4 Efficiency of doing work

The efficiency of doing work for all animals during the mask periods ranged from 15 to 30%, with an average of 20.9% (n = 36, s.e. 0.67) (Appendix 3).

5.4.5 SMR comparison

The SMR as measured by the Oxylog during resting periods longer than 15 minutes was on average 11.4% lower (n = 36, s.e. 1.26; range: -23.7 to 1.4%) than the ME maintenance requirements calculated with the use of the MAFF (1984) formula (Figure 12). A paired t-test showed a significant difference ($P<0.001$) between the two estimates of SMR (Appendix 5).

5.4.6 Comparison of the factorial method with the Oxylog measurements

Estimations of the extra energy expended during work during the mask periods (Total energy - SMR),, as measured by the Oxylog, ranged between 0.51 and 8.6 MJ. These results were on average 21.8% higher (range: -5.9 to 58.2%, n = 36, s.e. 0.07) than the estimations for the extra energy

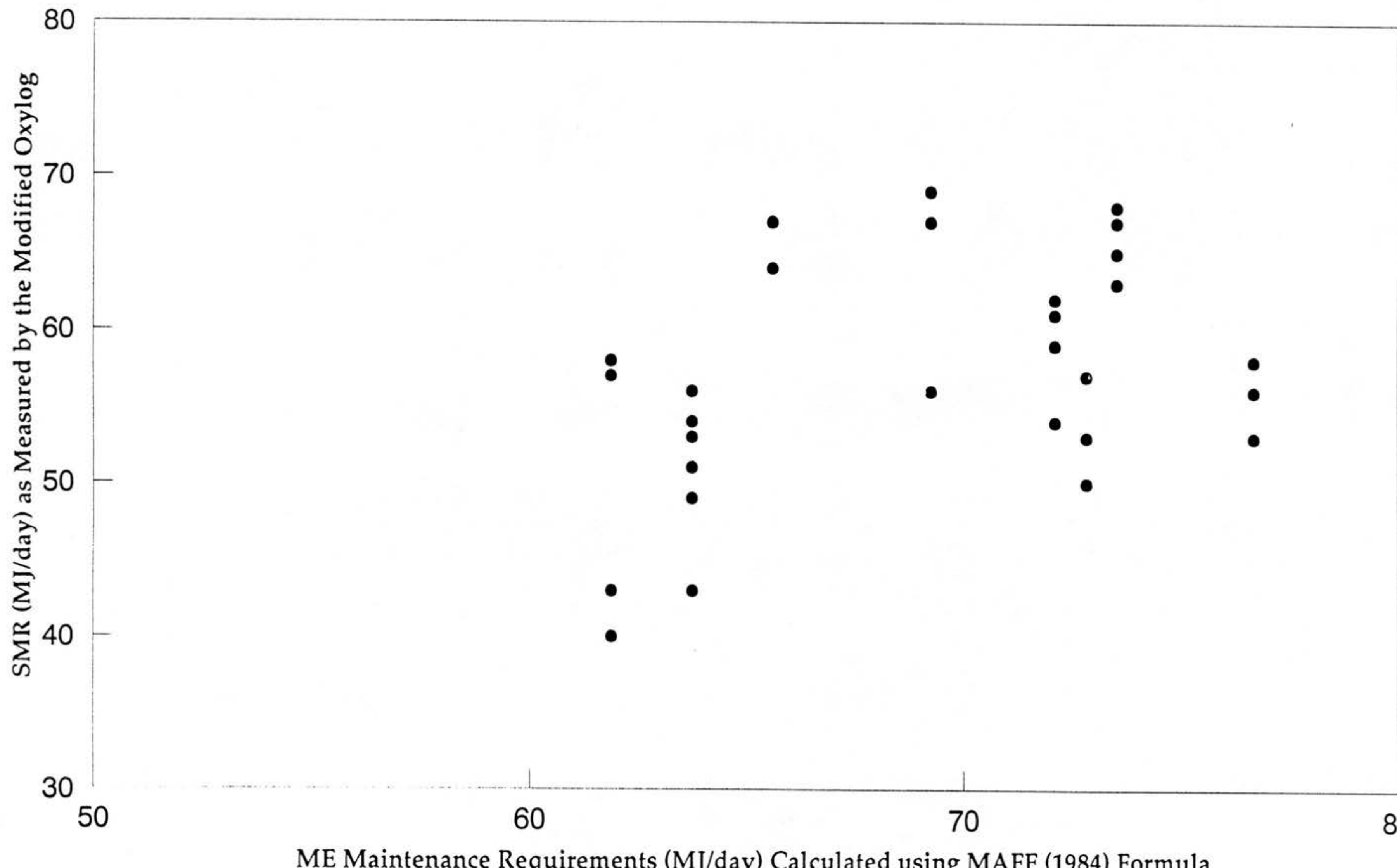


FIGURE 12

Comparison of ME maintenance requirements (MJ/day) as calculated using the MAFF (1984) formula and SMR (MJ/day) as measured by the modified Oxylog during the Colombian experiments.

expended during work during the mask periods as calculated by a factorial method (Lawrence, 1985), which ranged between 0.4 and 7.5 MJ (Figure 13). A paired t-test of the two results showed a significant difference ($P<0.001$) between the two estimations for the extra energy expended during work (Appendix 5).

5.5 COMPARISON OF BUFFALOES AND OXEN

5.5.1 O_2 consumption in resting periods

A two-sample t-test of the O_2 consumption while resting showed no significant difference between the buffaloes and oxen. O_2 consumption while resting averaged 0.016 $l/min/kg^{0.73}$ in buffaloes and 0.017 $l/min/kg^{0.73}$ in oxen (Table 8) (Appendix 3).

5.5.2 O_2 consumption in mask periods

There was no significant difference in the O_2 consumption during the mask periods between buffaloes, which averaged 0.025 $l/min/kg^{0.73}$, and oxen, which averaged 0.024 $l/min/kg^{0.73}$ (Table 8) (Appendix 3).

5.5.3 Ventilation volume in resting periods

A two-sample t-test of the ventilation volume while resting showed no significant difference between the buffaloes and oxen. Ventilation volume while resting averaged 0.73 $l/min/kg^{0.73}$ in buffaloes and 0.71 $l/min/kg^{0.73}$ in oxen (Table 8) (Appendix 4).

5.5.4 Ventilation volume in mask periods

There was no significant difference in the ventilation volume during the mask periods between buffaloes, which averaged 1.20 $l/min/kg^{0.73}$, and oxen, which averaged 1.20 $l/min/kg^{0.73}$ (Table 8) (Appendix 4).

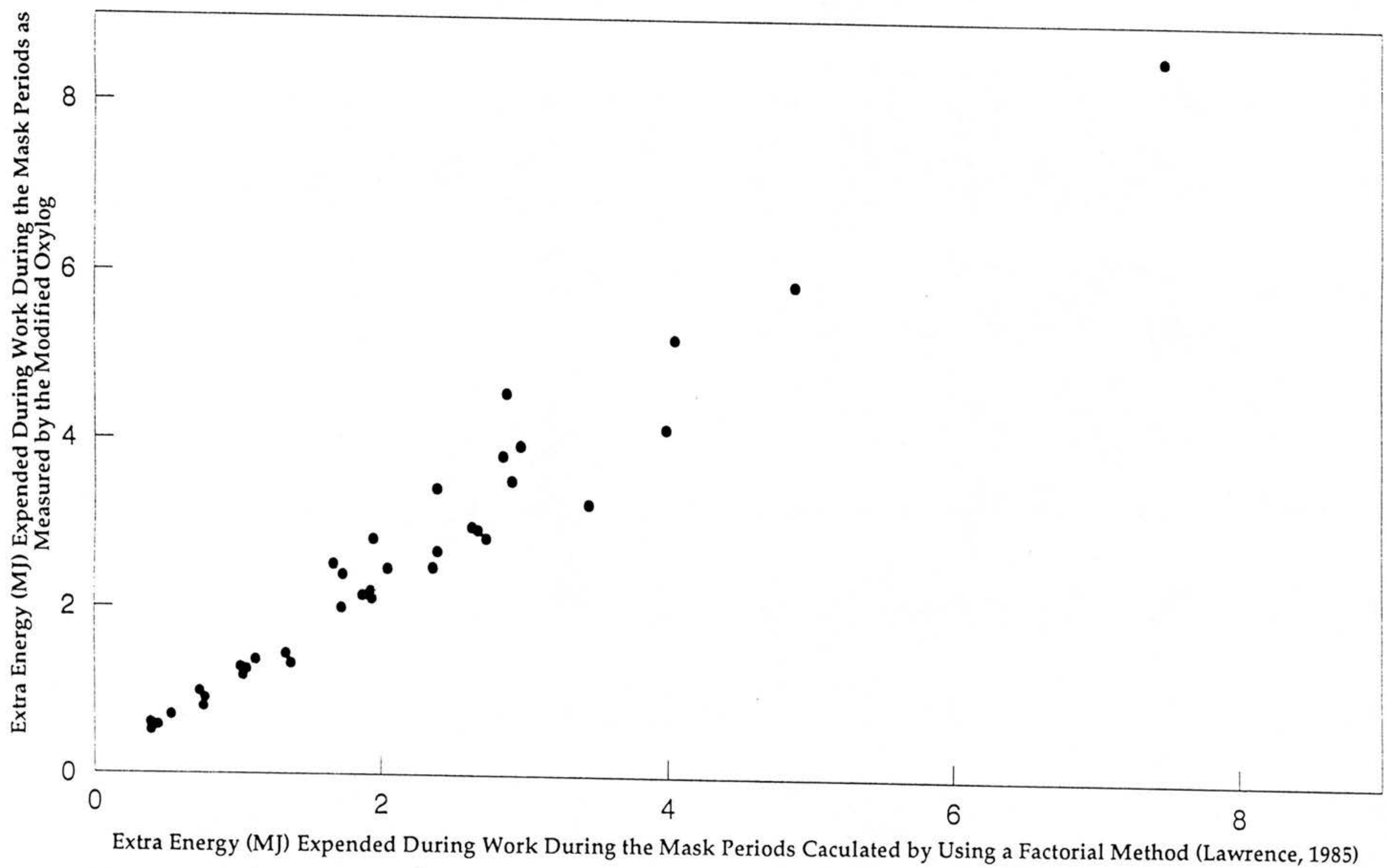


FIGURE 13

Comparison of extra energy (MJ) expended during work during the mask periods as measured by the modified Oxylog and as calculated by using a factorial method (Lawrence, 1985).

5.5.5 Work done

Work done by the buffaloes during the working day averaged 0.68 MJ and was not significantly higher than the work done by oxen working in the plantation, which averaged 0.51 MJ/day (Table 8) (Appendix 3).

5.5.6 Distance walked

The distance walked by the buffaloes in the plantation averaged 1939 m/day which was not significantly different from the total distance walked by the oxen which averaged 1721 m/day (Table 8) (Appendix 3).

5.5.7 Efficiency of doing work

Average efficiency of doing work by the buffaloes was 22.3%. This was significantly different ($P<0.001$) from the average efficiency of doing work by the oxen which was 18.1% (Table 8) (Appendix 3).

5.6 ENERGY REQUIREMENTS AND INTAKE OF PLANTATION ANIMALS

The total extra energy expended during work, as calculated using the Oxylog measurements, averaged 5.7 MJ/day. This meant that the experimental animals on average worked at 1.10 times their SMR (n = 36, range: 1.03 to 1.22, s.e. 0.008).

Observation of the grazing behaviour of the plantation animals led to the establishment of the following intake percentage of the available feedstuffs:

Brachiaria decumbens	—	30%
Pueraria phaseoloides	—	50%
3/4/5/6 (see Table 7)	—	20%

TABLE 8

Comparison of the O_2 consumption, ventilation volume, work done and efficiency of doing work of buffaloes and oxen working in an oil-palm plantation in Colombia.

	Buffaloes (n=24)	s.e.	Oxen (n=12)	s.e.	Statistical significance of difference
O_2 consumption resting periods $l/min/kg^{0.73}$	0.016	0.0004	0.017	0.0006	NS
O_2 consumption mask periods $l/min/kg^{0.73}$	0.025	0.005	0.024	0.005	NS
Ventilation resting periods $l/min/kg^{0.73}$	0.73	0.024	0.71	0.019	NS
Ventilation mask periods $l/min/kg^{0.73}$	1.20	0.034	1.20	0.036	NS
Work done (MJ)	0.68	0.07	0.51	0.06	NS
Distance walked (m)	1939	172	1721	218	NS
Efficiency of doing work (%)	22.3	0.78	18.1	0.84	***

NS = Not significant
* = P <0.05
** = P <0.01
*** = P <0.001

Using ME values for Latin American forages, published by the University of Florida (1974), it is assumed that q (ME/GE) equalled 0.5, this meant that 1 kg of Dry Matter Intake (DMI) contained on average 9.35 MJ ME.

Average weight of the experimental animals was 695 kg, which meant that average SMR, as measured by the Oxylog, was 57.4 MJ/day. Animals work 10.5 days out of every 14 days, hence the average energy expenditure over a 14 day period was 1.08 times SMR, or 62 MJ/day.

This would require an intake of 6.6 kg DMI. On the described diet estimated DMI (MAFF, 1984) is 9.2 kg. When the molasses fed was taken into account the calculated possible DMI was 9.5 kg (Appendix 6).

5.7 PROTEIN REQUIREMENT AND INTAKE OF PLANTATION ANIMALS

Although no conclusive evidence is available there seems to be very little extra requirement, over and above the maintenance requirements, for protein during work (Lawrence, 1985; Teleni and Hogan, 1989).

The metabolisable protein requirements of the plantation animals can be calculated using the formulas proposed by the Agricultural Development and Advisory Service [ADAS] (1991) (Appendix 7). The tissue protein requirement of the animals was calculated to be 311 g/day. Taking into account the efficiency of amino acid utilisation, the total amount of amino acids needed to be supplied to the tissues on a daily basis was 366 g.

On the diet described in Section 5.6, rumen microbes could provide 9 g of microbial protein per MJ. Hence, on the DMI estimated, 774 g of microbial protein could be synthesised by the rumen microbes, which would require a rumen degradable protein (RDP) intake of 815 g. The dietary intake of CP is 1419.1 g/day, of which between 60 and 80% was estimated to be RDP (MAFF, 1989). Therefore, enough RDP would be available to synthesise the maximum possible on this ME intake.

Of the 774 g of microbial protein that could be synthesised, 526 g of amino acids would be supplied to the tissues, which is 1.44 times the quantity estimated to be required.

5.8 HEALTH AND TEMPERAMENT

No serious health problems were encountered in the animals on the plantation. Occasional leg fractures were the main reason for the culling of animals. The incidence of skin injuries and hoof problems, however, was considerably higher in oxen. The same tendency was observed for tick related problems.

Moreover, the plantation harvesters preferred working with a buffalo to working with an ox, because buffaloes generally showed a greater willingness to work and tended to be more docile.

5.9 DISCUSSION

The Oxylog equipment worked satisfactorily throughout the experimental period. Some problems however, were encountered in the reading of the small digital LED displays, especially when they were directly exposed to bright sunlight. Another disadvantage to the experiments in the plantation was that animals could not be trained to the experimental procedures and the mask. As a result, the acceptance rate for the facemask was rather low (50%).

Brody (1945) reported resting O_2 consumptions, in growing Holstein and Jersey cattle in the weight range from 100 to 600 kg, which ranged from 0.015 to 0.020 $l/min/kg^{0.73}$. Resting O_2 consumption measurements were also in general agreement with Clar (1991), who reported an average value of 0.015 $l/min/kg^{0.73}$ $\pm$0.003. Resting O_2 consumption values reported by Zerbini, Gemeda, O'Neill, Howell and Schroter (1992) averaged 0.029 $l/min/kg^{0.73}$. The latter study was conducted at an altitude of 2400 m, and caution should be exercised when comparing physiological data from animals adapted to life under these conditions with data relevant to lower altitudes.

Resting O_2 measurements, as recorded by the open circuit gas analysis system, taken from Josey in the validation trial (Appendix 2) ranged from 0.018 $l/min/kg^{0.73}$ to 0.024 $l/min/kg^{0.73}$.

Brody (1945) reported resting ventilation volumes, in growing Holstein and Jersey cattle in the weight range from 100 to 600 kg, which ranged from 0.93 to 1.09 $l/min/kg^{0.73}$. Resting ventilation volumes reported by Hales and Findlay (1968) for young oxen weighing between 108 to 281 kg averaged 0.96 $l/min/kg^{0.73}$ (n = 12, s.e. 0.035) at 11°C and 1.02 $l/min/kg^{0.73}$ (n = 12, s.e. 0.123) at 30°C, which were both slightly higher than resting values in this experiment. Resting ventilation volume measurements were however in general agreement with Clar (1991) and with values reported by Zerbini *et al* (1992), which ranged from 0.69 to 0.76 $l/min/kg^{0.73}$.

Total work done and distance walked by the plantation draught animals during the working day was low in comparison with reports from other workers (Starkey, 1981; Barton, 1987; Pearson, 1989). Animals on average spent only 40 minutes working, whereas draught ruminants in other farming systems can be employed for over 6 h a day. However, the low EWT was inherent to the type of work the animals performed.

The efficiency of doing work, as measured by the Oxylog and the ergometer equipment, was low compared to laboratory values reported by Thomas and Pearson (1986) and Lawrence and Stibbards (1990). Various explanations can be provided for this. Firstly, in all calculations a value of 2.1 J/m/kg was used as the energy cost of walking. It was, however, unlikely that this was the real energy cost for walking in all cases because soil conditions varied quite substantially from day to day and from one part of the plantation to the other. Secondly, there was no control of the RQ during the mask periods. The calculation of energy expenditure assumed an RQ of 0.9.

Although the plantation animals were well-fed there was no guarantee that the experimental animals were mostly metabolising carbohydrates during the mask periods. Thirdly, the majority of the work done by the plantation animals was done in very short bursts. The initial force needed to get a cart moving would be high, after which the actual time that the cart moved was short. It was likely that the maximum rate at which O_2 could be supplied to the muscles was exceeded and that anaerobic regeneration of adenosine triphosphate (ATP) from creatine phosphate, adenosine diphosphate (ADP) and the conversion of pyruvate to lactate during anaerobic glycolysis provided the additional energy at a rapid rate to the muscle cells. The energy yield from this process is much lower than that from oxidative processes. The 'topping up' of the energy reserves after these short bursts of maximum effort could have reduced the efficiency of doing work (Pearson, 1985).

Measurements for SMR were on average 11.4% lower than the calculated ME requirements. As mentioned before SMR, as measured during this experiment is not strictly comparable with ME, which is a 24 h average and includes the total heat increment over the day.

Estimations for the extra energy expended during work, as measured by the Oxylog and calculated by a factorial method, were significantly different. These results are explained by the fact that the factorial method assumed one efficiency for doing work (30%), whereas the actual efficiency, as measured by the Oxylog and ergometer instruments, for doing work varied between 15 and 30%. Moreover, the use of a constant value for the energy cost of walking might also have influenced these results.

Work done by the buffaloes was higher than the work done by the oxen. It was observed that harvesters working with oxen preferred the ani-

The efficiency of buffaloes for doing work was significantly higher than the efficiency for doing work by oxen. The higher average body weight of the buffaloes is a definite advantage in the short bursts of work needed to get the carts moving. Contrary to reports made by Pearson (1989), where buffaloes were considered to be at a disadvantage while continuously carting loads in direct sunlight, this was not the case in the present example. Work was less, and mainly carried out in the shade. Hence for the specific work in oil-palm plantations and similar environments the buffalo might be superior to oxen. Lawrence and Stibbards (1990) suggested that buffaloes were maybe just naturally more efficient, which was supported by these results.

The calculation of the energy and protein requirements for the animals working in the plantation, showed that the available forages were adequate in the provision of the necessary diet. Animals worked on average at 1.08 times SMR only, and the general inference of all these observations was that the buffaloes and oxen are far from optimally utilized, because draught animals can work up to 1.7 times their maintenance requirements (Lawrence, 1986; Barton, 1987; Pearson, 1990). This however, was inevitably due to the type of work the animals were used for.

CHAPTER SIX
THE INFLUENCE OF SOIL CONSISTENCY ON THE ENERGY EXPENDITURE AND NUTRIENT REQUIREMENTS OF BUNAJI (*BOS INDICUS*) DRAUGHT BULLS WORKING IN THE SUB-HUMID ZONE OF NIGERIA

6.1 INTRODUCTION

The experimental work carried out in Colombia proved that the Oxylog was robust enough for use in the field and satisfactory results were obtained during the experimental trials in the oil-palm plantation. The field studies showed that the acceptance rate of the mask for animals which were not trained was fairly low (50%). Training during the experimental period in Colombia was impossible, because the animals were employed daily in the harvesting.

The Colombian experiments established that it was very difficult to read the small digital LED displays on the Oxylog, in particular when the sun was shining on them.

Overall, the instrumentation proved to be a reliable method for the estimation of energy expenditure in the field. It was felt that the instruments could be used to check on the established laboratory calorific values for the different activities that draught animals are asked to perform in the field.

The energy cost of walking and working in cattle has been extensively researched (Hall and Brody, 1934; Brody, 1945; Ribiero *et al* 1977; Lawrence and Richards, 1980; Lawrence and Stibbards, 1990) (Table 3). The majority of these measurements were carried out either while animals were walking and working on a treadmill or in a circular race. The values obtained under these conditions have consequently been used in a factorial method (Lawrence, 1985, 1987a; Mathers, 1984; Graham, 1985; Mathers *et al*, 1985) to estimate the energy expenditure of animals working in the field.

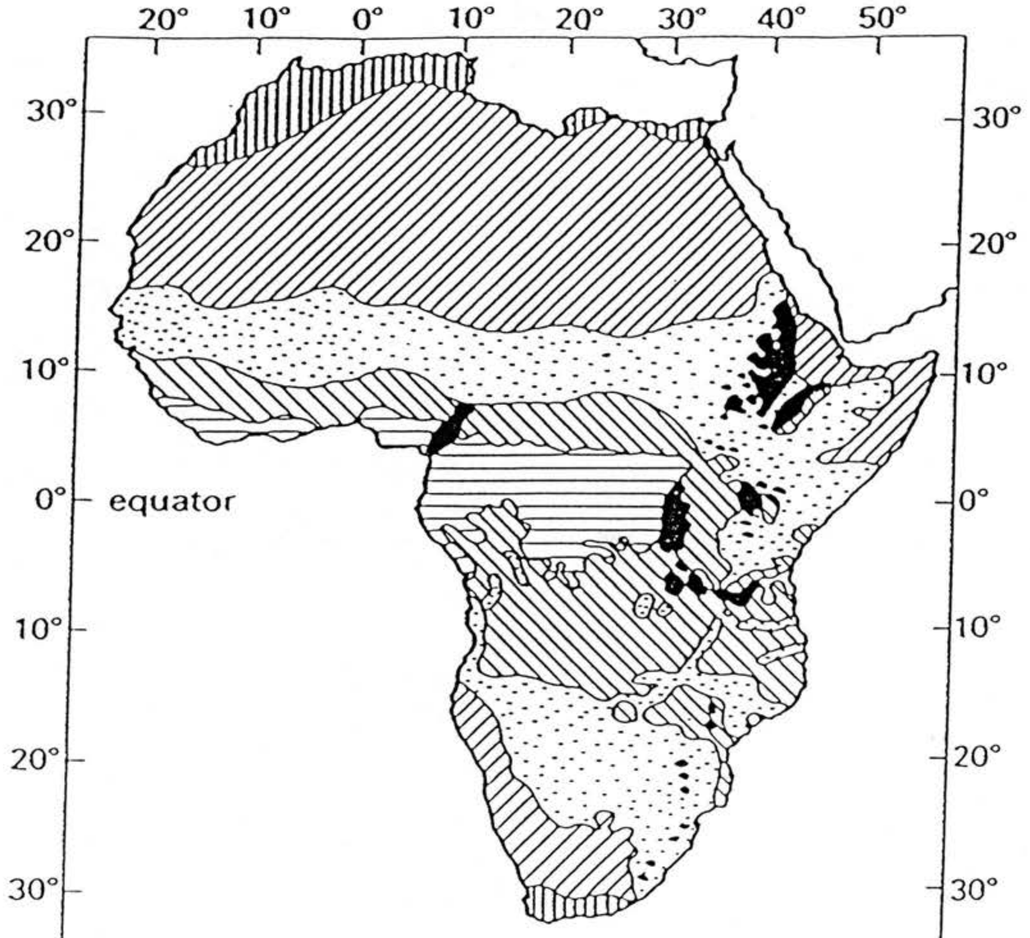
Generally, however, draught animals do not work on concrete or perfectly flat and firm surfaces. Energy consumption connected with walking can make up for 40 to 60% of the total energy expenditure when draught animals are working on hard surfaces, so this is likely to be even higher on unlevel or soft terrain. This has undoubtedly caused errors in the estimation of draught animal energy expenditure in the field when the laboratory based values were used in a factorial method, as was suspected in the results of the Colombian field trial.

White and Yousef (1978) first reported on the extra energy expended on different terrains in reindeer as their energy expenditure for walking increased significantly (24%) in the change from dry to wet tundra. In an experiment carried out at the CTVM by Lawrence (1987b), animals walked and worked in 300 mm deep mud in a circular track and these results were compared with the results obtained while the animals performed the same tasks when the track was not covered in mud. The associated energy expenditures were monitored using a classic open circuit system available at the CTVM (Richards and Lawrence, 1984) (Figure 6). The results of this work showed that there was virtually no difference in the efficiency of doing work in mud or on concrete, but there was approximately a 90% increase in the energy expenditure for walking. This experiment provided only one different soil condition and was still carried out in the laboratory environment. Moreover, it is more strenuous for draught animals to walk in small circles than in a straight line, because the muscles in the body on the outside of the circle need to stretch, while the other muscles in the body, on the inside of the circle, need to contract. Another problem encountered during this experiment was that the animals improved in fitness and also showed a long-term adaptation to the work they were doing, especially since they were relatively inexperienced at the start. The logistics of this type of laboratory experiment however make it impossible to overcome these problems.

An important feature of agriculture in the sub-humid zone of Africa (Figure 14) is the presence of seasonally inundated low-lying valleys or fadamas, which make up for about 7% of the total cultivatable area of Africa (International Livestock Centre for Africa [ILCA], 1990). The valley bottoms are formed by the accumulation of fine soil particles. They are flat with a high clay or very fine sand content and inclined to be waterlogged. In contrast the surrounding soil (known as the uplands), from which the fine particles are washed, is coarse and gritty though still fairly fertile.

In Nigeria, the valley bottoms are used almost exclusively by small-scale farmers for rice production and by peripatetic Fulani herdsmen as a source of winter grazing for their cattle. The uplands are used principally for the production of food crops such as maize and sorghum.

The development of Nigeria's agriculture largely depends on the productivity of the numerous small-scale farmers. It is this sector of the population that produces the bulk of the staple food consumed in the country. Manual labour is predominantly used to cultivate the cropped area. The resulting bottle-necks at peak labour periods (land preparation, weeding and harvesting) limit not only the area under cultivation, but also the yield per capita. With finite amounts of cultivable land available and a growing population, utilisation of both upland and fadama land will have to be intensified.



Marking indicating the sub-humid zone.

FIGURE 14

Map of Africa showing the location of the sub-humid zone.

Until recently animal traction had been restricted to the Northern Sahelian zone of Nigeria, but with the disappearance of the tsetse challenge, ILCA commenced work on the introduction of animal traction into the sub-humid zone. During this work, it again became apparent that the consistency of the soil had a profound effect on the energy consumption of working animals. Hence, the ILCA project site offered an excellent place for the application of the Oxylog, since the major reason for the adaptation and validation of the instrument was the possibility to measure the energy consumption of draught animals during their normal working routine. Experiments were designed, to quantify the energy cost of the various tasks that draught animals are asked to perform on soils of different consistencies in the fadama areas.

6.2 MATERIALS AND METHODS

6.2.1 Animals and feeding

A total of eight Bunaji bulls (*Bos indicus*) were used in the initial upland walking trials of the Nigerian experiments. Subsequent measurements were carried out using six animals only, because one pair of bulls was not completely trained for field work. All experimental determinations were made at Kufana village, 80 km south east of Kaduna in the sub-humid zone of Nigeria, from September 1991 to May 1992. The ages, weights and pairing of the animals are shown in Table 9.

The animals in Kufana were used throughout the year for cultivation, weeding and transportation for the ILCA project and had been in constant use over the past three years.

TABLE 9

Ages, weights and pairing of experimental Bunaji bulls used in the Nigerian experiments.

Bull No.	Age	Weight	Pairing
111	7	413	A
112	5	341	B
113	7	420	A
114	5	398	B
397	4	358	C
398	4	335	C
663	6	402	D*
770	6	358	D*

* Animals only used for 'walking Upland'

The animals were fed 3 kg of concentrates each at 06.00 h (one h before the start of the experiments) to ensure that they were mainly metabolising carbohydrates during the experimental periods. Hence, the RQ value during the experimental period probably varied between 0.8 and 1.

The animals had continuous access to natural pasture, water and a salt lick. Ambient temperatures throughout the experimental period ranged between 22 and 31°C with the relative humidity ranging between 0.30 and 0.85.

6.2.2 Experimental methods

The animals were trained to wear the facemask, to carry the analysing and recording unit of the Oxylog and to the general experimental routine over a period of four weeks. This was essential to obtain high acceptance rates of the mask (in this case 100%) and to ensure that the animals breathed and worked normally while wearing the instruments, as suggested by the experiments carried out in Colombia. During the first two weeks of training, each animal wore a dummy mask for 0.5 h/day. Ballast equivalent to the weight of the Oxylog was placed in the Oxylog pouch on the girth strap to balance the counterweight (Plate 10).

In the third and fourth week of training, animals were fitted with the complete Oxylog instrumentation and facemask. Each animal was trained for 0.75 h/day.

Respiration rate/min, before and after the fitting of the facemask, was checked at the start of all experiments and no differences were found in any of the experimental animals.

During the experiments animals walked and worked in pairs, as during the normal working routine of the farmers on the farm, and wore a neck yoke. The wearing of the Oxylog apparatus was rotated on a daily basis (Plate 11).

The measurements were made on three soils with different consistency: upland (firm, an animal does not sink into the soil), dry fadama (an animal sinks 50 - 250 mm into the soil), wet fadama (an animal sinks > 250 mm)

Both the modified Oxylog (Section 3.3) and ergometer (Lawrence and Pearson, 1985) (Section 3.4) were used to monitor the performance of the animals enabling measurements of O_2 consumption (l), ventilation volume (l), and where applicable distance travelled (m) and work done (J). Because the Oxylog displays are very small and difficult to read, a panel with two voltmeters, giving the readings for minute O_2 consumption and minute ventilation volume, and two digital counters, recording total O_2 consumption and total ventilation volume, was manufactured. This data viewing panel was connected to the recorder output on the Oxylog via a long cable, hence facilitating the manual 'data logging' (Plate 12).

PLATE 10

Training animals to wear the mask during the experimental period in Nigeria.

PLATE 11

Bunaji bull in Nigeria wearing the complete Oxylog instrumentation.

PLATE 12

The dataviewing panel connected to the recorder output on the Oxylog analysis and recording unit.

The implement was connected to the middle of the yoke by a chain, with the load cell (Section 5.3.2) fitted between the implement and chain, so that all the force produced by the animals was channelled through the load cell. Hence the work done per animal was obtained by dividing the measured values by two. DADF was calculated by dividing the work done by the distance walked.

All parameters were recorded every minute on the minute. During a typical experiment each animal went through the following routine:

(a) Rest — 20 minutes

(b) Walk — 20 minutes

(c) Work (i.e. pulling) — 60 minutes (three times 20 minutes)

(d) Walk — 20 minutes

(e) Rest — 20 minutes (Figure 15)

Each activity was monitored for at least 20 minutes. This ensured that the animal reached a metabolic 'steady state' before measuring the energy consumption associated with each particular activity and it allowed for the response time of the Oxylog. In well-fed animals, energy expenditure during each activity can be calculated by multiplying the average O_2 consumption (l/min) by 20.7 kJ (eq. 3).

To enable continuous movement, the animals both walked and worked in large circles (minimum diameter 30 m). Animals were allowed to choose their own walking/working speed, but this then was maintained throughout the measurement period.

Generally, heavier animals use more energy for walking, hence the results were expressed as J/m/kg (ARC, 1980; King, 1981; Lawrence and Stibbards, 1990).

The energy cost of walking (E_w) on each soil was defined as:-

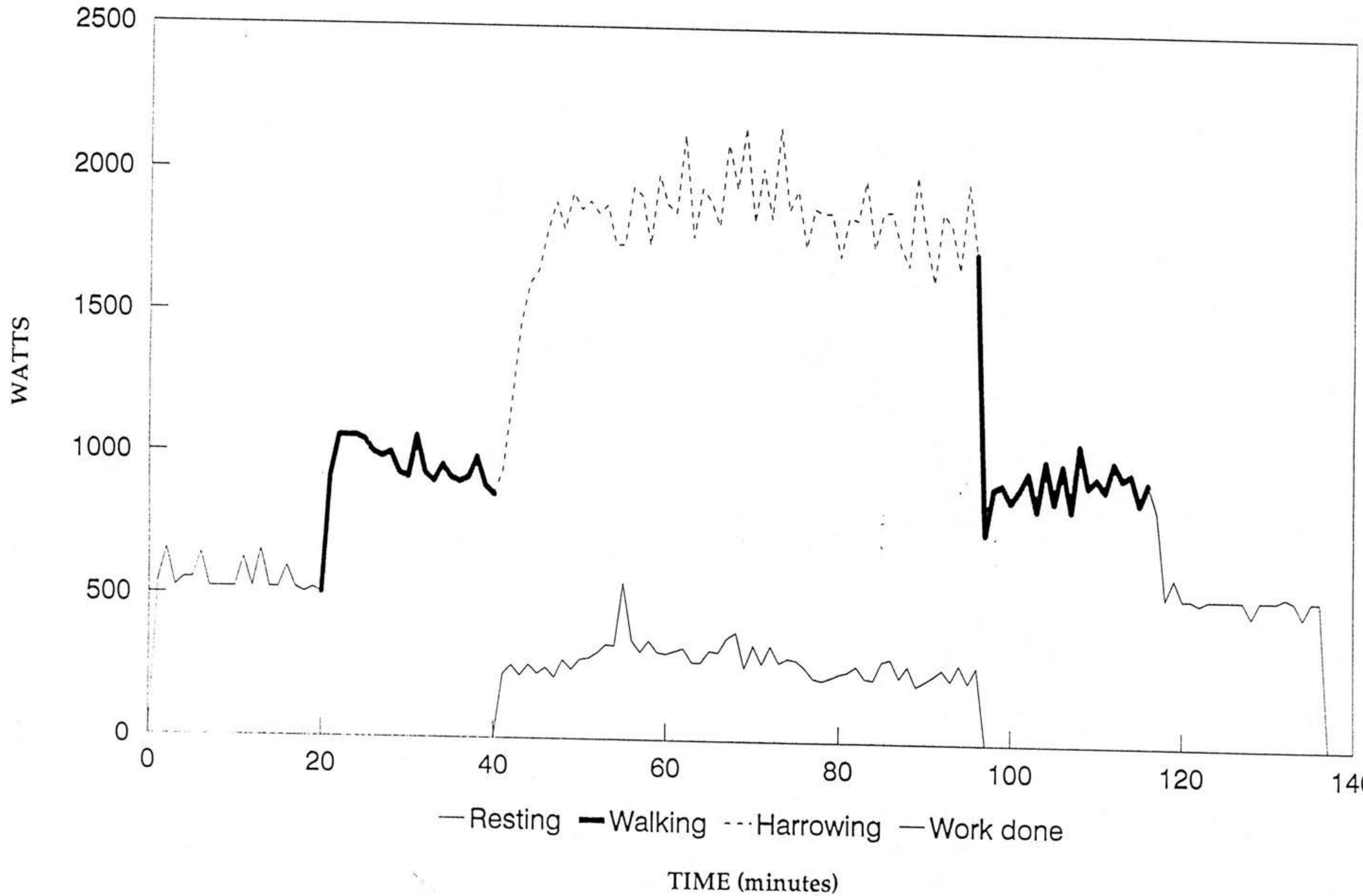


FIGURE 15

Typical energy consumption pattern of Bunaji draught bulls during the experimental periods in Nigeria.

E_w (J/m walked per kg liveweight) = [energy used while walking — energy used while standing still for the same length of time] / [distance walked (m) x live weight (kg)]

The energy cost of doing work was defined as in Section 5.3.3.

The energy costs for both standing and walking were taken as the average of the first and final measurement.

Whilst ploughing, the lead animal walked on land which had already been ploughed and when harrowing both animals walked on ploughed land. This had a significant influence on the energy expended for walking. It was therefore decided to divide E_w into $E_{w\ unploughed}$ and $E_{w\ ploughed}$ for the three soil consistencies investigated. Statistical analysis of the results were carried out using the analysis of variance on Minitab statistical software (Ryan *et al*, 1985).

6.3 RESULTS

6.3.1 Training

Pair A and B of the experimental animals (Table 9) were ready for experimental observation after two weeks of training, but pair C and D of the experimental animals took substantially more time and patience to train. At the end of the four week period however, all experimental animals were fully accustomed and at ease with the experimental procedures and the wearing of the facemask.

6.3.2 Dataviewer

The manufacture of the dataviewer proved to be a great success. Not only did it make data recording a lot easier, it also meant that data could be recorded away from the animals without any disturbance to them. Compared to a datalogger, where data can only be checked after it has been transferred to a computer, the dataviewer has the advantage of early trouble shooting as readings can be checked continuously and any problems with the instrumentation can be corrected immediately.

6.3.3 Ventilation volume

Ventilation volumes of the experimental animals as measured by the Oxylog (Appendix 8) during the different activities are shown in Table 10.

TABLE 10

Ventilation volumes of Bunaji draught bulls in Nigeria during various activities as measured by the modified Oxylog.

Activity		n	Average ventilation volume ($l/min/kg^{0.73}$)	s.e.
Resting		107	1.01	0.02
Walking upland		38	1.98	0.05
Walking ploughed upland		17	2.48	0.09
Walking dry fadama		13	2.03	0.09
Walking ploughed dry fadama		15	2.36	0.12
Walking wet fadama		19	2.06	0.09
Walking ploughed wet fadama		18	2.78	0.08
Harrowing upland		18	3.2	0.05
Harrowing dry fadama		18	2.87	0.11
Harrowing wet fadama		18	2.86	0.10
Ploughing upland	a	6	3.56	0.09
	b	12	2.35	0.11
Ploughing dry fadama	a	7	3.42	0.18
	b	11	2.73	0.08
Ploughing wet fadama	a	3	3.11	0.002
	b	15	2.41	0.09

a Animal walked on soil already ploughed
b Animal walked on unploughed soil

6.3.4 O_2 consumption during resting periods

O_2 consumption of the experimental animals, as measured by the Oxylog, during the resting periods averaged 0.022 l/min/kg$^{0.73}$ (n = 107, s.e. 0.0004) (Appendix 9). Average SMR calculated from these results, using the mean weight of the experimental animals (76.15 kg$^{0.73}$), was 34.7 MJ ME/day. Maintenance requirements calculated using the MAFF (1984; Section 5.3.3) formula averaged 44.2 MJ ME/day, which was 27.4% higher than the SMR calculated from the Oxylog results.

6.3.5 Energy cost of walking

6.3.5.1 *Upland* (Table 11) (Appendix 10) (Figure 16)

$E_{w\ unploughed\ upland}$ averaged 1.47 J/m/kg and was significantly lower than $E_{w\ ploughed\ upland}$, which averaged 2.87 J/m/kg. Walking speed on the unploughed upland ranged between 1.27 and 0.62 m/s with an average of 0.97 m/s and was significantly higher than the speed of walking on the ploughed upland which ranged between 1.17 and 0.57 m/s with an average of 0.83 m/s.

6.3.5.2 *Dry fadama* (Table 11) (Appendix 11) (Figure 16)

$E_{w\ unploughed\ dry\ fadama}$ averaged 1.76 J/m/kg and was significantly lower than $E_{w\ ploughed\ dry\ fadama}$, which averaged 3.76 J/m/kg. Walking speed on the unploughed dry fadama varied between 1.04 and 0.68 m/s with an average of 0.87 m/s and was significantly higher than the speed of walking on the ploughed dry fadama, which ranged between 1.00 and 0.63 m/s with an average of 0.74 m/s.

6.3.5.3 *Wet fadama* (Table 11) (Appendix 12) (Figure 16)

$E_{w\ unploughed\ wet\ fadama}$ averaged 3.30 J/m/kg and was significantly lower than $E_{w\ ploughed\ wet\ fadama}$, which averaged 8.58 J/m/kg. Walking speed on the unploughed wet fadama varied between 0.96 and 0.69 m/s with an

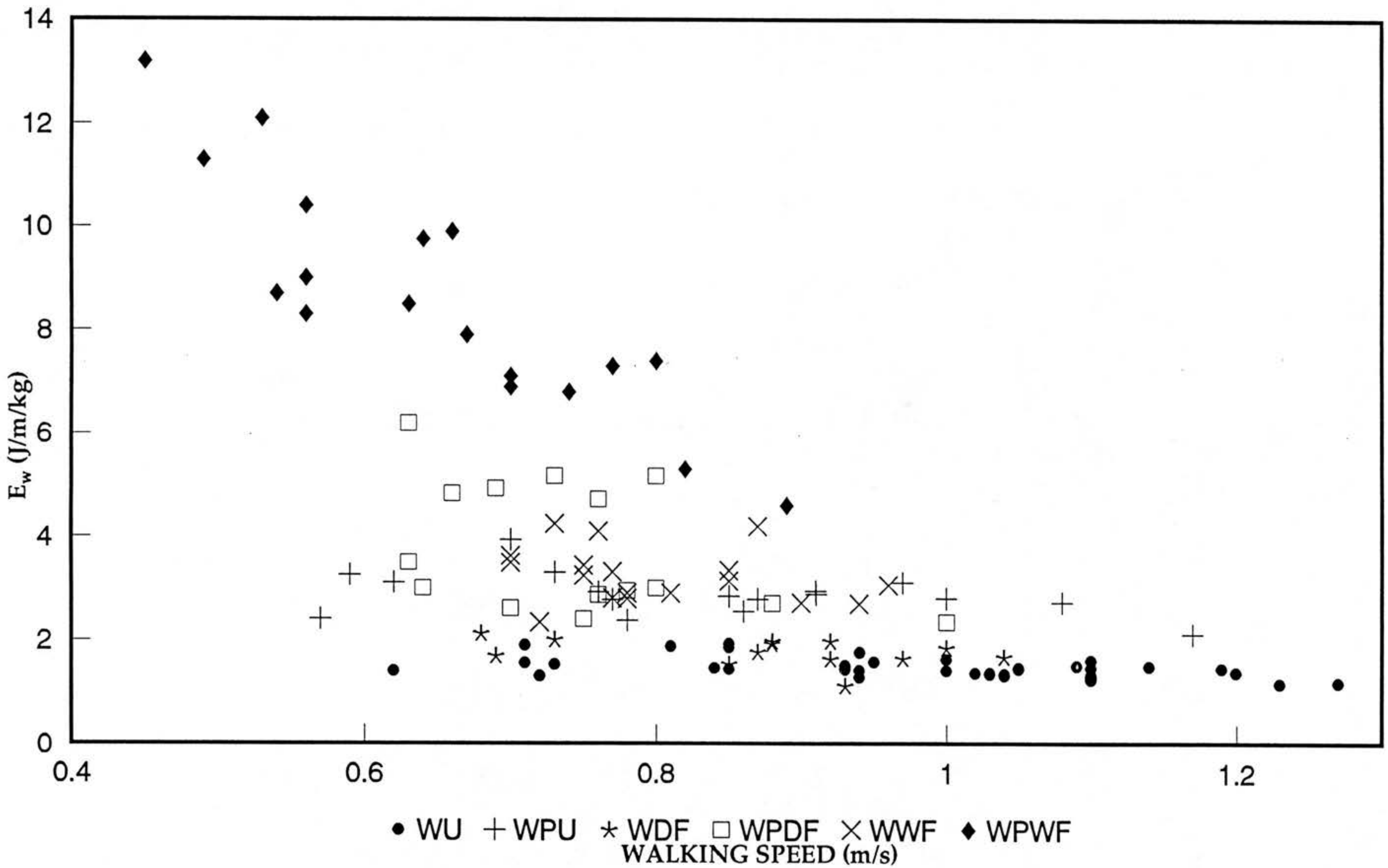


FIGURE 16

E_w (J/m/kg) versus walking speed (m/s) of eight Bunaji bulls on three different soil consistencies during the experimental period in the sub-humid zone of Nigeria.

TABLE 11

The energy cost and speed of walking of Bunaji draught bulls on soils of different consistency in the sub-humid zone of Nigeria.

Soil	n	Average energy for walking E_w (J/m per kg)	s.e.	Statistical significance of difference	Average walking speed (m/s)	s.e.	Statistical significance of difference
Unploughed upland	38	1.47	0.03	***	0.97	0.08	**
Ploughed upland	17	2.87	0.10		0.83	0.08	
Unploughed dry fadama	13	1.76	0.07	***	0.87	0.05	**
Ploughed dry fadama	15	3.76	0.32		0.74	0.05	
Unploughed wet fadama	19	3.30	0.14	***	0.80	0.04	***
Ploughed wet fadama	18	8.58	0.53		0.65	0.06	

average of 0.80 m/s and was significantly higher than the speed of walking on the ploughed wet fadama which ranged between 0.89 and 0.45 m/s with an average of 0.65 m/s.

6.3.6 Energy cost of doing work

6.3.6.1 *Upland* (Table 12) (Appendix 13)

There was no significant difference between the efficiency of ploughing and harrowing upland. The efficiency for ploughing and harrowing averaged 0.31 and 0.33 respectively.

The average speed of walking while ploughing, 0.55 m/s, was significantly lower than the average speed of walking while harrowing, 0.66 m/s.

The DADF during ploughing was 658 N and was significantly lower than the DADF during harrowing, 779 N.

6.3.6.2 *Dry fadama* (Table 12) (Appendix 14)

There was no significant difference between the efficiency of ploughing and harrowing dry fadama. The efficiency for ploughing and harrowing averaged 0.30 and 0.32 respectively.

There was no significant difference between the average speed of walking while ploughing and the average speed of walking while harrowing, 0.53 and 0.51 m/s respectively.

The DADF during ploughing was 1130 N and was significantly lower than the DADF during harrowing, 1250 N.

6.3.6.3 *Wet fadama* (Table 12) (Appendix 15)

There was no significant difference between the efficiency of ploughing and harrowing wet fadama. The efficiency for ploughing and harrowing averaged 0.31 and 0.31 respectively.

TABLE 12

Efficiency of doing work, speed of walking and DADF of Bunaji draught bulls on different soil consistencies in the sub-humid zone of Nigeria.

Soil	n	Average efficiency	s.e.	Average Walking speed (m/s)	s.e.	Statistical significance of difference	Average DADF (N)	s.e.	Statistical significance of difference
Ploughing upland	18	0.31	0.01	0.55	0.05	**	658	78	***
Harrowing upland	18	0.33	0.02	0.66	0.06		779	72	
Ploughing dry fadama	18	0.30	0.02	0.53	0.05		1130	64	**
Harrowing dry fadama	18	0.32	0.01	0.51	0.04		1250	20	
Ploughing wet fadama	18	0.31	0.01	0.46	0.01		1265	58	***
Harrowing wet fadama	18	0.31	0.01	0.47	0.02		1450	68	

There was no significant difference between the average speed of walking while ploughing and the average speed of walking while harrowing, 0.46 and 0.47 m/s respectively.

The DADF during ploughing was 1265 N and was significantly lower than the DADF during harrowing, 1450 N.

One pair of bulls, C, walked significantly faster during work on all soil consistencies ($P<0.05$) compared to the other pairs.

6.4 DISCUSSION

In the statistical analysis of the data it was recognised that repeated measurements on individual animals were used as independent variables.

While, in the strict sense, this is not usually appropriate, it was felt here that the energy cost of walking would vary with the physical environment in which the individual was being monitored, so that individual observations, on occasions, within animals would have as much meaning as observations on one occasion between animals.

It is clear from the data (Appendix 9-11) that variation within animals, between observations, was as great as between animals. Furthermore, work done on one day was not expected to influence the energy cost of walking on a subsequent day, and it was therefore deemed reasonable to include the repeat measures (as has been done by others working in this areas e.g. Ribeiro *et al*, 1977; Lawrence and Richards, 1980; Mathers, 1984; Lawrence, 1985; Lawrence and Pearson, 1985; Sneddon, 1986; Lawrence and Stibbards, 1990; Pearson, 1990; Clar, 1991; Zerbini *et al*, 1992).

The main difference from the experimental methodology in Colombia, was the relative control over the experimental animals in Nigeria. This advantage was best reflected in the fact that animals could be trained to the experimental methods and to the facemask. A total of four weeks was spend on training. It is difficult to give precise recommendations on training requirements, as this will be animal dependent. In this experiment two of the pairs were fully trained after two weeks only, whereas the other two pairs needed four weeks to reach this level. In general, less training is required for animals that have been handled more. It seems however, advisable to devote a minimum of two weeks to training in all cases.

A further advantage was the fact that it was possible to have some control over the RQ of the animals by feeding them 3 kg of concentrate 1 h before the start of the experiments, which ensured that they were metabolising mostly carbohydrates.

The dataviewer greatly facilitated data recording and was preferred to the use of a datalogger, because it offered a continuous check on the data collected. Overall, the instruments used were robust and proved once again to be a good and reliable tool for field measurements of energy expenditure in draught ruminants.

The energy cost of walking on a flat, firm soil measured in this experiment, proved to be substantially lower than values previously reported by various other workers (Table 3), who reported values between 1.9 and 2.1 J/m/kg. In this experiment the energy cost of walking on flat, firm soil averaged 1.47 J/m/kg. Comparison of these results with general formulae proposed by Tucker (1969) and Taylor, Schmidt-Nielsen and Raab (1970) to predict the energy cost of locomotion, using an average liveweight of 387 kg for the animals in the study, showed that the formula of Taylor *et al* (1970) gives a value of 1.0 J/m/kg and that of Tucker (1969) predicts a value of 3.3 J/m/kg. As pointed out by Lawrence and Stibbards (1990), the measurements on which Tucker based his formula included the resting metabolic rate. This in conjunction with the fact that animals have on average an SMR which is 26% higher on working days than on non-working days (Lawrence *et al*, 1989), lent more support to Tucker's (1969) higher estimate.

King (1981) proposed a general formula for the energy expenditure of walking in Zebu cattle of 200 kg fed at maintenance. He based his formula for the energy expenditure on the walking speed. Substitution of the average walking speed on unploughed upland (0.97 m/s) in this experiment gave a value of 1.15 J/m/kg, which was probably the best prediction of the three formulae considered.

The higher values obtained for E_w in the laboratory setting can be explained by the fact that animals are either forced to walk at a certain speed on a moving treadmill surface and probably spent energy balancing and slipping or animals have to walk in small circles in a circular race, which has a higher energetic cost. In the present experiment animals were allowed to choose their own walking speed, which was then maintained throughout the measurement period.

The lower value for E_w observed in this experiment can have significant consequences when calculating the daily energy requirements of ruminants.

Another crucial observation was that the E_w on ploughed upland doubled or more than doubled. The same tendency was observed on all soils. These observations have nutritional implications for draught animals working on soils of differing consistencies. When animals were ploughing with a mouldboard plough, the lead animal walked on land which had already been ploughed and as a result spent between 20 and 25% more energy than its partner while doing the same job. Moreover, the walking speed went down as the energy expenditure for walking went up. These results were consistent with reports made by Lawrence (1987b), who observed a 90% increase in energy expenditure for walking when animals changed from walking on concrete to walking in 300 mm mud. In the walking experiments a decrease in soil consistency was linked to a decrease in walking speed and an increase in the energy expenditure for walking, but the situation when animals are ploughing or harrowing is slightly more complicated. Whereas the same trend of animals slowing down on the wetter soils can be observed, other factors which have an impact on the walking speed during work are the type of implement and the draught force needed for the specific cultivation.

Although animals will spend approximately the same amount of energy during a full working day (Lawrence, 1985), whether they are doing 'light' or 'heavy' work, the energy expenditure per unit area and the actual cultivation time needed will be much higher. When animals are employed for part of the day only, the extra energy expenditure of the lead animal while ploughing has to be taken into account. When animals are harrowing, both animals will spend more energy for walking, and as a result less energy will be available during the working day for doing useful work.

The present experiments were carried out using one particular type of animal only. It would be interesting to see if the use of smaller or larger animals, or animals of different constitution, have an influence on the calorific values associated with walking on soil of differing consistencies.

The efficiency of doing work was not influenced by the consistency of the soil. These results were again consistent with results obtained by Lawrence (1987b). This however, was expected, as to obtain the efficiency of doing work the real energy cost for walking was subtracted from the extra energy expended during work. The fall in efficiency observed by Lawrence and Smith (1988), when animals were working on muddy soils in Costa Rica, was likely to be caused by an increase in E_w, which may also have been one of the reasons for the low efficiency for doing work recorded in the Colombian experiments.

Overall, the efficiencies measured were in the same range as the values reported for Brahman cattle, although substantially lower than the efficiency of doing work for buffaloes (Lawrence and Stibbards, 1990). Efficiency for doing work reported by ARC (1980) and Thomas and Pearson (1986) were also 3 to 4% higher.

ILCA's work on the introduction of animal traction into the sub-humid zone of Nigeria has shown that, especially in the cultivation of the fadama for rice, animal traction is an attractive option. Substantial time savings are made at the most critical period of the year so that crops can be planted on time. However, for several farmers the pressure and shortage of labour at the start of the rainy season might still prove too much. Pilot trials have shown that it was possible to plough and harrow a large proportion of the fadama area in Kufana during the dry season using ox-drawn implements, whereas in all but a few places the soil was too hard for manual cultivation until the onset of the rains (Lawrence, personal communication). Ox-drawn cultivation in the dry season had several advantages. Time was not a constraint and cultivation could be done more thoroughly. Working conditions were less stressful because it was dry and cool. The exposure of the soil to the winter sunshine killed a lot of the pests and weeds. Most important of all the rice crop could be sown in the fadama as soon as sufficient rain had fallen and the farmers could devote all their time and energy to the cultivation of their upland food crops.

The present results, further point out that it would make sense to cultivate the fadama soils in the dry season from an animal point of view. Not only are the animals likely to be in a better condition at that time of the year (Smith, 1981b), but also the soil is not too wet and E_w will be lower which leaves more energy for doing useful work. The E_w increased as soils got further inundated with water, but also the DADF rose quite substantially. As a result more time, effort and energy was needed to cultivate a unit area.

Overall, E_w in this experiment ranged from 1.47 to 8.58 J/m/kg, which can have a profound effect on the energy expenditure of draught animals and hence on their nutritional requirements.

CHAPTER SEVEN
CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

7.1 THE VALIDATION TRIAL

The new facemask for use with the modified Oxylog proved to be a major improvement on the first design, which was described by Dijkman (1989). Not only was the mask comparatively simple to manufacture, it also fitted more than just one animal and was very durable.

Results of the validation trials showed good agreement between measurements made by the Oxylog and the open circuit gas analysis system, especially when the separate measurement periods were pooled over the total experimental period. A paired t-test of the validation results showed that there was no significant difference between the two observations. On average the Oxylog overestimated O_2 consumption, as measured by the open circuit gas analysis system, by 1.5%.

7.2 THE COLOMBIAN EXPERIMENTS

In the first major field trial with the modified Oxylog in an oil-palm plantation in Colombia, the instruments and mask both proved robust throughout the experimental period. The Oxylog, however, is equipped with two small digital LED displays. It was difficult to record data from these displays without disturbing the animal, especially when they were exposed to direct sunlight.

Results obtained were generally in agreement with other available methods for the estimation of draught animal energy expenditure in the field.

Animals employed in the oil-palm plantation did not perform a lot of work and the efficiency of doing work calculated from the experimental results was generally low compared to values established during laboratory experiments (Lawrence and Stibbards, 1990). The use of anaerobic metabolism by the animals in getting the cart moving, was thought to be a factor in the relatively low efficiency for doing work during the experimental observations.

The soil conditions in the plantation varied quite dramatically from day to day and from one part of the plantation to the other. It was suspected that this had an effect on the energy expended for walking. Efficiency calculations were influenced by this because the E_w was set at 2.1 J/kg/m. Moreover, during the experiments in the plantation there was no control over the feeding of the experimental animals and hence their RQ during the mask periods. This was likely to influence the calculation of the energy expenditure from the O_2 consumption, because eq. 3 assumes an RQ of 0.9.

Buffaloes were significantly more efficient in doing work and seemed to be the preferred animals rather than cattle for pulling carts in the plantation. Not only were they more obedient and easy to work with, but their higher average bodyweight was thought to be of advantage in the short bursts of work needed to get a cart moving.

Other difficulties connected with the use of the Oxylog instrument for measuring energy expenditure in the field were also identified. Animals in the plantation could not be trained to the experimental methods and as a result the acceptance rate of the facemask was only 50%. Furthermore, some of the animals that did accept the mask appeared to be nervous, which had an obvious influence on their SMR. Animals do not like wearing masks and as a general rule a lot of time and patience is needed to ensure that animals accept the mask and breath normally whilst wearing it.

7.3 THE NIGERIAN EXPERIMENTS

The experimental conditions in Nigeria were in many ways ideal. Animals were trained to the experimental procedures over a period of four weeks and as a result the mask acceptance rate was a 100%. Furthermore, the animals were fed 3 kg of concentrates 1 h before the start of the measurements with the Oxylog, ensuring that they were mainly metabolising carbohydrates.

The dataviewer, which was connected to the datalogger output, made data recording and checking not only a lot easier, but it was also possible to record data without disturbance to the animal.

The experimental results showed that the efficiency of doing work was not influenced by the consistency of the terrain that the animals were working on. Efficiencies obtained were similar to those reported by Lawrence and Stibbards (1990). The E_w, however, proved to be significantly influenced by the consistency of the soil. Values obtained ranged between 1.47 J/kg/m when walking on firm, flat upland soil, to 8.58 J/kg/m when walking on ploughed, wet fadama soil. This confirmed that the use of a value of 2 J/kg/m for the E_w in a factorial method is unlikely to represent the true cost of E_w in all cases.

Lawrence (1985), reported that whether animals were used for 'light' or 'heavy' work, this had little influence on their total energy expenditure when animals were employed over a full working day. This means that when animals spend more energy for walking, less energy will be available for useful work, and as a result the time and energy input needed per unit area cultivated will increase.

When animals are employed for part of the day only, the extra energy expended when walking on soils of differing consistencies will have to be accounted for.

It was also of great interest to observe the dramatic increase in E_w after ploughing, on the three soil types investigated, in the energy expended by the animals for walking. When animals are ploughing in teams with a mould-board plough, the lead animal walks on the soil which has already been cultivated. This has obvious implications for the lead animal as it will spend between 20 to 25 % more energy while doing the same job as the other animal in the team. Research carried out by Lawrence (1985) in Costa Rica showed that the feed quality and level of management influenced the total work output of a pair of animals. The present observations emphasise the benefits of the use of a stronger and better fed beast as the lead animal.

The presented experimental results indicate that it makes sense to cultivate the fadama in the dry season. Whilst a system of dry season cultivation can be appropriate and more efficient from our scientific point of view, the implications, in a range of areas, of the actual implementation of such an idea will need careful consideration. For a start, fadamas constitute one of the main dry season grazing reservoirs for the cattle of the peripatetic Fulani herdsmen and cultivation of these inland valleys during the dry period would restrict their use for grazing.

7.4 ESTIMATION OF THE ENERGY COST OF WALKING ON SOILS WITH DIFFERENT CONSISTENCIES

The Nigerian experiments showed clearly that when animals were allowed to choose their own walking speed on soils of different consistencies, they would slow down as the soil got less firm. No scientific classification of the soils was carried out during this experiment, but the observations could be used as an easy method to approximate the E_w on soils with different consistencies, when no instruments are available to carry out the necessary measurements. The method is as follows:

Measure out a 100 m track on the soil type that animals are working on. Let the animals walk the track 10 times, choosing their own walking speed, and measure the average time needed to walk the distance. Table 12 can thereafter be used for the approximation of the E_w.

TABLE 13

Proposed walking speed bands for the estimation of the energy cost of walking on soils with different consistencies.

Walking speed (m/s)	E_w (J/m/kg)
0.85 - 1	1.5 - 2.0
0.75 - 0.85	2.0 - 3.5
0.5 - 0.75	3.5 - 8.0

The proposed bands give a rough indication for E_w. Nevertheless, it is expected that they would apply to a variety of draught ruminants on a number of different soils. It would be of interest to determine whether similar bands apply to animals of a lower bodyweight and to animals with different anatomies and constitutions (e.g. long-legged Hariana cattle or small N'Dama cattle).

7.5 FURTHER APPLICATION OF THE MODIFIED OXYLOG

The modified Oxylog proved to be a reliable and useful tool in the measurement of the energy expenditure of working draught animals. The use of a facemask in this method generally restricts its use and the length of application. It is for example impossible to use the modified Oxylog to observe the energy consumption of grazing animals. Measurement periods have to be restricted to 3 to 4 h at the time, because animals need to drink and eat and normally do not like to wear the mask for longer periods. Furthermore, the mask makes application of the technique on farmers' animals impossible. Animals need at least 2 to 4 weeks of training, to wear the mask and to get acquainted with the experimental methods, before reliable measurements can be made. Another obvious disadvantage is that the Oxylog measures only O_2. Hence, the RQ needs to be known relatively accurately which can pose problems, as was thought to be the case during the Colombian trials. Although the changes needed to modify the Oxylog for use on animals are comparatively simple, a degree of skill and practice is needed in the manufacture of the scaled-up flowmeters, valves and masks. The Oxylog however remains a good and relatively cheap method for accurate observations on the energy requirements in a variety of animals. The further application of the method has to be mainly sought in the obtaining of baseline data on the energy requirements of the various types of draught animals. The influence of body condition, nutrition and training on the energy consumption during the day and during work and the acquisition of data on the nutritional requirements of animals working in specific farming systems are other areas of application of the modified Oxylog. Variations in the SMR due to, for example, food intake and work could be monitored by taking hourly spot measurements at well chosen intervals during the day.

The existing 'breath by breath' techniques, apart from all the obvious difficulties connected to animals wearing a facemask, are likely to be the only feasible method available for the estimation of energy expenditure in the field for several years at least. The use of this equipment however, due to the various complications mentioned earlier, is likely to stay restricted to field work within research organisations.

7.6 FUTURE RESEARCH

The use of the DLW technique, due to the possible widespread application, is an exciting prospect for the measurements of energy expenditure in draught animals. However, it has been impossible to secure funding to carry out the necessary validation trials in draught ruminants , as of yet. A project proposal to validate and test the DLW method, as put forward to ILCA, is presented in Appendix 16. With the increasing difficulty to obtain funding for all kinds of research, it seems unlikely that this method will become available for use in draught ruminants in the next 10 years.

Future research should not only be directed at the measurement of energy expenditure. Other main research areas, which are intricately connected with the nutritional requirements of draught animals, are the problems associated with the calculation of the amount of food necessary to provide the metabolisable energy to meet these expenditures:

1) The metabolisable energy content of many tropical feeds is not known with any degree of accuracy.
2) It is often difficult to predict the voluntary food intake when animals are fed to appetite.

New feed evaluation systems such as those proposed by Ørskov and Ryle (1990), however, are a step in the right direction to solving these problems.

Much other localised research into the more efficient use of draught animals in specific farming systems remains necessary and an example of such a proposed integrated research project is presented in Appendix 17.

It has been mentioned earlier that over the past 10 years draught animal research has developed greatly, so that it is now possible to predict nutritional requirements with greater accuracy. Whereas a variety of questions still need answering, the development of suitable instruments has made this research possible. The modified Oxylog is likely to play a major part in this research for many years to come.

REFERENCES

ADAS (1991). *Report of the Interdepartmental Working Party on the Protein Requirements of Ruminants.* ADAS Subcentre, Staplake Mount, Starcross, Exeter.

ARC (1980). *The Nutrient Requirements of Ruminant Livestock.* Commonwealth Agricultural Bureaux, Farnham Royal, Slough.

BALLAL, M.A. and McDONALD, I.A. (1982). An evaluation of the Oxylog as a portable device with which to measure oxygen consumption. *Clinical Physiology and Physiological Measurement*, **3**, 57—65.

BARKER, R. and HAYAMI, Y. (1984). Practicas de control de maiezas como un componente en los sistemas de produccion de arroz. *Arroz*, **33**, 331, 17—27.

BARTON, D. (1987). *Draught Power Supply, Nutrition and the Work Output of Draught Animals in Bangladesh.* Report prepared for the Ford Foundation, Dhaka and FSRDP. Bangladesh Agricultural University, Mymensingh.

BIRD, A.R., CHANDLER, K.D. and BELL, A.W. (1981). Effects of exercise and plane of nutrition on nutrient utilization by the hind limb of the sheep. *Australian Journal of Biological Science*, **34**, 541—550.

BLAXTER, K.L. (1962). *The Energy Metabolism of Ruminants.* Hutchinson, London.

BLAXTER, K.L., CLAPPERTON, J. L. and WAINMAN, F.W. (1966). The extent of differences between six British breeds of sheep in their metabolism, feed intake and utilisation and resistance to climatic stress. *British Journal of Nutrition*, **20**, 283—294.

BLAXTER, K.L. and JOYCE, J.P. (1963). The accuracy and ease with which measurements of respiratory metabolism can be made with tracheostomized sheep. *British Journal of Nutrition*, **17**, 523—537.

BLAXTER, K.L. and ROOK, J.A.F. (1964). The heat of combustion of the tissues of cattle in relation to their chemical composition. *British Journal of Nutrition*, **7**, 83.

BROCKWAY, J.M. (1978). Escape from the chamber, alternative methods for large animal calorimetry. *Proceedings of the Nutrition Society*, **37**, 13—19.

BROCKWAY, J.M. and McEWAN, E.H. (1969). Oxygen uptake and cardiac performance in the sheep. *Journal of Physiology*, **202**, 661—669.

BROCKWAY, J.M. and WHITELAW, F.G. (1970). Methods of measuring energy in the field. In: *Proceedings of the Fifth Symposium on the Energy Metabolism of Farm Animals* (Eds. A. Schurch and C. Wenk), pp. 233—236. EAAP Publication No. 13. Juris and Verlag, Zurich.

BRODY, S. (1945). *Bioenergetics and Growth*. Reinhold, New York. (reprinted in 1964, Haffner, New York)

BROUWER, E. (1965). Report of the sub-committee on constants and factors. In: *Proceedings of the Third Symposium on the Energy Metabolism of Farm*

Animals (Ed. K.L. Blaxter), pp. 441—443. EAAP Publication No. 11. Academic Press, London.

CLAR, U. (1991). *Entwicklung einer Feldmethode zur Messung des Energie Umsatzes bei Zugtieren*. PhD thesis, University of Hohenheim.

CORBETT, J.L., FARRELL, D.J., LENG, R.A., McCLYMONT, G.L. and YOUNG, B.A. (1971). Determination of the energy expenditure of penned and grazing sheep from estimates of carbon dioxide entry rate. *British Journal of Nutrition*, **26**, 277—291.

CORBETT, J.L., LENG, R.A. and YOUNG, B.A. (1969). Measurement of energy expenditure by grazing sheep and the amount of energy supplied by volatile fatty acids produced in the rumen. In: *Proceedings of the Fourth Symposium on the Energy Metabolism of Farm Animals* (Eds. K.L. Blaxter, J. Kielanowski and G. Thorbeck), pp. 177—186. EAAP Publication No. 12. Oriel Press Ltd.

COWARD, W.A. and PRENTICE, A.M. (1984). Simultaneous measurement of maternal and infant energy expenditure together with breast milk output using $D_2{}^{18}O$ method. In: *Human Energy Metabolism* (Ed. A.J.H. Van Es), pp. 136—138. E.C. Workshop, Wageningen.

CRESSWELL, E. and HARRIS, L.E. (1961). An improved tracheal cannula for use in indirect calorimetry and other studies. *The Veterinary Record*, **73**, 343—344.

CTVM (1987). *Ergometer Instruction Manual*. University of Edinburgh.

DIJKMAN. J.T. (1989). *The Measurement of Energy Consumption of Draught Oxen in the Field, The Oxylog for Oxen*. MSc thesis, CTVM, University of Edinburgh.

DIJKMAN, J.T. (1992). A note on the influence of negative gradients on the energy expenditure of donkeys walking, carrying and pulling loads. *Animal Production*, **54**, 153—156.

DOUGLAS, C.G. (1911). A method for determining the total respiratory exchange in man. *Journal of Physiology* (London), **42**, 17—18.

DOUNIS, E., STEVENTON, R.D. and WILSON, R.S.E. (1980). The use of a portable oxygen consumption meter (Oxylog) for assesing the efficiency of crutch walking. *Journal of Medical Engineering and Technology*, **4**, 296—298.

FAO (1972). *Manual on the Employment of Draught Animals in Agriculture*. FAO, Rome, Italy.

FARRELL, D.J., CORBETT, J.L. and LENG, R.A. (1970). Automatic sampling of blood and ruminal fluid of grazing sheep. *Research in Veterinary Science*, **11**, 217—220.

FLATT, W.P., WALDO, D.R., SYKES, J.F. and MOORE, L.A. (1958). A proposed method of indirect calorimetry for energy metabolism studies with large animals under field conditions. In: *Symposium on Energy Metabolism* (Eds. G. Thorbek and H. Aersoe), pp. 101—109. EAAP Publication No. 8, Copenhagen, Denmark.

FRISCH, J.E. and VERCOE, J.E. (1969). Liveweight gain, food intake and eating rate in Brahman, Africander and Shorthorn x Hereford cattle. *Australian Journal of Agricultural Research*, **20**, 1189—1195.

FRISCH, J.E. and VERCOE, J.E. (1976). Maintenance requirements, fasting metabolism and body composition in different cattle breeds. In: *Energy Metabolism in Farm Animals* (Ed. M. Vermorel). EAAP Publication No. 19, Clermont-Ferrand, France.

FRISCH, J.E. and VERCOE, J.E. (1977). Food intake, eating rate, weight gains, metabolic rate and efficiency of feed utilisation in *Bos taurus* and *Bos indicus* crossbred cattle. *Animal Production*, **25**, 343—358.

GOE, M.R. and McDOWELL, R.E. (1980). *Animal Traction, Guidelines to Utilisation*. Cornell International Agriculture Mimeo. Ithaca, N.Y. Cornell University.

GRAHAM, N.Mc. (1985). Relevance of the British metabolisable energy system in the feeding of draught animals. In: *Draught Animal Power for Production* (Ed. J.W. Copland), pp.96—98. ACIAR Proceedings Series No. 10.

HAGGARTY, P. (1991). Potential of the doubly labelled water method for estimating heat production in farm animals. *Journal of Agricultural Science* (Cambridge), **117**, 141—148.

HAGGARTY, P., McGAW, B.A. and FRANKLIN, M.F. (1988). Advantages and limitations with the heavy water technique of measuring energy expenditure. Obesity in Europe 88. In: *Proceedings of the 1st European*

Congress on Obesity (Eds. P. Bjorntorp and S. Rossner), pp. 365—370. John Libbey and Company Ltd, London, U.K.

HAGGARTY, P., McGAW, B.A., FULLER, M.F., CHRISTIE, S.L. and WONG, W.W. (1991). Water hydrogen incorporation into body fat in pigs, effect on the double/triple labelled water methods. *American Journal of Physiology*, **260** (Regulatory Integrative Comparative Physiology 29), R627—R634.

HALES, J.R.S., and FINDLAY, J.D. (1968). Respiration of the ox. Normal values and the effect of exposure to hot environments. *Respiration Physiology*, **4**, 333—352.

HALL, W.C. and BRODY, S. (1934). The energy cost of horizontal walking in cattle and horses of various ages and body weights. University of Missouri Agricultural Experiment Station. *Research Bulletin*, **208**.

HARRISON, M.H., BROWN, G.A. and BELYAVIN, A.J. (1982). 'The Oxylog', an evaluation. *Ergonomics*, **25**, 809—820.

HAVSTAD, K.M. and MALECHEK, J.C. (1982). Energy expenditure by heifers grazing crested wheatgrass of diminishing availability. *Journal of Range Management*, **35**, 447—450.

HOLMES, C.W., STEPHENS, D.B. and TONER, J.N. (1976). Heartrate as a possible indicator of the energy metabolism of calves kept out-of-doors. *Livestock Production Science*, **3**, 33—341.

HORNICKE, H., EHRLEIN, H.-J., TOLKMITT, G., NAGEL, M., EPPLE, E., DECKER, D. KIMMICH, H.P. and KREUZER, F. (1974). Method for continuous oxygen consumption measurements in exercising horses by telemetry and electronic data processing. In: *Proceedings of the 6th Symposium on Energy Metabolism of Farm Animals.* (Eds. K.H. Menke, H.-J. Lantzsch and I.R. Reichl) pp. 257—260. EAAP Publication No. 14, Juris, Zurich.

HOWELL, P.J. and O'NEILL, D.H. (1990). *ILCA contract final report, Document OD/90/05.* AFRC Engineering Overseas Division, Silsoe, U.K.

HUMPHREY, S.J.E. and WOLFF, H.S. (1977). The Oxylog. *Journal of Physiology*, **267**, 12p.

IITA, (1986). *Annual Report.* Ibadan, Nigeria.

ILCA, (1990). *Annual Report and Programme Highlights.* Addis Ababa, Ethiopia.

JONES, P.J., WINTHROP, A.L., SCHOELLER, D.A., SWYER, P.R., SMITH, J., FILLER, R.M. and HEIM, T. (1987). Validation of doubly labeled water for assesing energy expenditure in infants. *Pediatric Research,* **21**, 241—246.

KIBLER, H.H. and BRODY, S. (1951). University of Missouri Agricultural Experiment Station. *Research Bulletin*, **473**.

KIBLER, H.H. and BRODY, S. (1954). University of Missouri Agricultural Experiment Station. *Research Bulletin*, **574**.

KING, J.M. (1981). *Ungulate Water Turnover in Tropical Africa*. Monograph No. 6. ILCA, Addis Ababa, Ethiopia.

KISU, M. (1985). Automatic field work apparatus. In: *Proceedings of the International Conference on Soil Dynamics and Commemoration of the 50th Anniversary of the National Tillage Machinery Laboratory*, pp. 1039—1045. ARS, USDA, Auburn, Alabama.

KOFRANYI, E. and MICHAELIS, H.F. (1940). Ein tragbar apparat zur bestimmung des gasstoffwechsels. *Arbeits physiologie*, **11**, 148—150.

KRUGER, L. (1957). Die bestimmung der arbeitfahigkeit bei pferd und rind durch leistungsprufungen, physiologische und pshysiologische messwerte und durch die exterieurbeuteilung (I). *Z.Tierzuchtig., Zuchtungsbiol*, **69**(4), 289—320.

KRUGER, L. (1958). Die bestimmung der arbeitfahigkeit bei pferd und rind durch leistungsprufungen, physiologische und pshysiologische messwerte und durch die exterieurbeuteilung (II). *Z.Tierzuchtig., Zuchtungsbiol.* **70**(1), 1—20.

LAL, R. (1991). Soil tillage for agricultural sustainability. *Soil and Tillage Research*, **20**, 2—4.

LAWRENCE, P.R. (1985). A review of the nutrient requirements of draught oxen. In: *Draught Animal Power for Production* (Ed. J.W. Copland), pp. 59—63. ACIAR Proceedings Series No. 10.

LAWRENCE, P.R. (1986). The energy expenditure of working oxen. In: *Proceedings of the IV World Congress of Animal Feeding*, p. 26, Madrid.

LAWRENCE, P.R. (1987a). Nutrient requirements of working ruminants. In: *An Introduction to Working Animals* (Ed. J.L. Falvey), pp. 61—79. MPW Australia, Melbourne.

LAWRENCE, P.R. (1987b). Mud, mud, glorious mud. *Draught Animal News*, **7**, 1—2.

LAWRENCE, P.R., BUCK, S.F. and CAMPBELL, I. (1989). The metabolic rate of oxen after work. *Proceedings of the Nutrition Society*, **48**, 153A.

LAWRENCE, P.R. and CAMPBELL, I. (1987). The resting metabolism, rate of methane production and longterm RQ of draught oxen. *Draught Animal News*, **8**, 1—3.

LAWRENCE, P.R. and PEARSON, R.A. (1985). Factors affecting the measurement of draught force, work output and power of oxen. *Journal of Agricultural Science* (Cambridge), **105**, 703—714.

LAWRENCE, P.R. and PEARSON, R.A. (1989). Measurement of energy expenditure in working animals, Methods for different conditions. In: *Draught Animals in Rural Development* (Eds. D. Hoffmann, J. Nari and R.J. Petheram), pp.155—165. ACIAR Proceedings Series No. 27.

LAWRENCE, P.R., PEARSON, R.A. and DIJKMAN, J.T. (1991). Techniques for measuring whole body energy expenditure of working animals: A critical review. In: *Isotope and Related Techniques in Animal Production* *and Health*, pp. 211—232. International Atomic Energy Agency, Vienna.

LAWRENCE, P.R. and RICHARDS, J.I. (1980). The energy cost of walking in some tropical draught animals. *Animal Production*, **30**, 455.

LAWRENCE, P.R. and SMITH, A.J. (1988). A better beast of burden. *New Scientist*, **1609**, 49—53.

LAWRENCE, P.R., SOSA, R. and CAMPBELL, I. (1989). The underlying 'resting' energy consumption of oxen during work. *Proceedings of the Nutrition Society*, **48**, 154A.

LAWRENCE, P.R. and STIBBARDS, R.J. (1990). The energy cost of walking carrying and pulling loads on flat surfaces by Brahman cattle and swamp buffaloes. *Animal Production*, **50**, 29—39.

LIFSON, N., GORDON, G.B. and McCLINTOCK, R. (1955). Measurement of total carbon dioxide production by means of D_2O^{18}. *Journal of Applied Physiology*, **7**, 704—710.

LIFSON, N., GORDON, G.B., VISSCHER, M.B. and NIER, A.O. (1949). The fate of utilized molecular oxygen and the source of the oxygen of respiratory carbon dioxide, studied with the aid of heavy oxygen. *Journal of Biological Chemistry*, **180**, 803—811.

LIFSON, N. and McCLINTOCK, R. (1966). Theory of use of turnover rates of body water for measuring energy and material balance. *Journal of Theoretical Biology*, **12**, 46—74.

LUBIGAN, R.T., ESTORNINOS, L.E. and MOODY, K. (1984). Efficiency of different weed control methods for dry-seeded wetland rice. *Weed Abstracts*, **033—02803**.

LUNING, H. A. (1984). Rice research and development in West Africa, Problems and perspectives. *Netherlands Journal of Agricultural Science*, **32**, 3, 193—204.

MAFF (1984). *Energy Allowances and Feeding Systems for Ruminants.* Reference Book 433. MAFF, London, HMSO.

MAFF (1989). *Tables of Rumen Degradability Values for Ruminant Feedstuffs.* ADAS Feed Evaluation Unit, Stratford upon Avon, Warwickshire.

MARTIN, D.G. and TELENI, E. (1989). Fatigue in buffaloes on different work loads. *Draught Animal Power Project Bulletin*, **8**, 2—6.

MATHERS, J.C. (1984). Nutrition of draught animals. In: *Animal Energy in Agriculture in Africa and Asia*, pp. 60—66. FAO Expert Consultation on Appropiate Use of Animal Energy in Agriculture in Africa and Asia, 15—19 Nov. 1982. FAO Animal Production and Health Paper 42. FAO, Rome.

MATHERS, J.C., PEARSON, R.A., SNEDDON, J.C., MATTHEWMAN, R.W. and SMITH, A.J. (1985). The use of draught cows in agricultural systems with particular reference to their nutritional needs. In: *Milk Production in Developing Countries* (Ed. A.J. Smith), pp 476—496. CTVM, University of Edinburgh, U.K.

McLEAN, J.A., STOMBAUGH, D.P., DOWNIE, A.J. and GLASEBY, C.A. (1983). Body heat storage in steers (*Bos taurus*) in fluctuating thermal environments. *Journal of Agricultural Science* (Cambridge), **100**, 315—322.

McLEAN, J.A. and TOBIN, G. (1987). *Animal and Human Calorimetry*. Cambridge University Press, Cambridge.

MIDWOOD, A.J., HAGGARTY, P., McGAW, B.A. and ROBINSON, J.J. (1989). Methane production in ruminants, its effect on the doubly labelled water method. *American Journal of Physiology*, **26**, R1488—R1495.

MIDWOOD, A.J., HAGGARTY, P., McGAW, J., ROBINSON, J. and FULLER, M.F. (1989). Application of the heavy water technique for the measurement of energy expenditure to production animals. In: *Proceedings of the Eleventh Symposium on the Energy Metabolism of Farm Animals* (Eds. Y. Honing and W.H. Close), pp. 341—344. EAAP Publication No. 19. Lunteren, The Netherlands.

MOUNTCASTLE, U.B. (1980). *Medical Physiology* (14th edn.). C.V. Mosby, St. Louis.

O'BRIEN, D.T. and PRICE, E.C. (1983). Interaction between fertilizer and weed control methods in the Philippine upland rice. Estimates from farmers' fields. *IRRI Research Paper Series*, No. 97.

O'NEILL, D., HAYTON, S. and SIMS, B. (1989). Measurement of draught animal performance. In: *Draught Animals in Rural Development* (Eds D. Hoffmann, J. Nari, R.J. Petheram), pp. 264—271. ACIAR-Proceedings Series No. 27.

ØRSKOV, E.R. and RYLE, M. (1990). *Energy Nutrition in Ruminants*. Rowett Research Services Ltd, Aberdeen.

PEARSON, R.A. (1985). Physiological changes associated with work: Some lessons from the horse. In: *Draught Animal Power for Production* (Ed. J.W. Copland), pp. 51—56. ACIAR Proceedings Series No. 10.

PEARSON, R.A. (1989). A comparison of draught cattle (*Bos indicus*) and buffaloes (*Bubalus bubalis*) carting loads in hot conditions. *Animal Production*, **49**, 355—363.

PEARSON, R.A. (1990). A comparison of the work performance of Jersey crossbreds and local oxen in the Koshi hills of East Nepal. *Pakhribas Technical Paper*, No. **130**. Pakribas Agricultural Centre, Kathmandu, Nepal.

PETHERAM, R.J., GOE, M.R. and ABIYE ASTATKE (1989). *Approaches to Research on Draught Animal Power in Indonesia, Ethiopia And Australia*. Graduate School of Tropical Veterinary Science, James Cook University, Townsville, Australia.

PETHICK, D. (1984). Energy metabolism of skeletal muscle. In: *Ruminant Physiology — Concepts and Consequences*, pp. 227—287. Proceedings of a Symposium. University of Western Australia, Perth.

PINGALI, P., BIGOT, Y. and BINSWANGER, H. (1987). *Agricultural Mechanisation and the Evolution of Farming Systems in Sub-Saharan Africa.* John Hopkins University Press, Baltimore, USA.

POSNER, J.L., CRAWFORD, E.W. and KAMUANGA, M. (1991). Farmer participation in on-farm trials, The case of lowland rice in southern Senegal. *Journal for Farming Systems Research Extension*, **2**, 125—134.

PRESTON, T.R. and LENG, R.A. (1987). *Matching Ruminant Production Systems with Available Resources in the Tropics and Sub-Tropics.* Penambul Book, Armidale.

PULLAR, J.D., BROCKWAY, J.M. and McDONALD, J.D. (1967). A comparison of direct and indirect calorimetry. In: *Proceedings of the Fourth Symposium on the Energy Metabolism of Farm Animals* (Eds. K.L. Blaxter, J. Kielanowski and G. Thorbeck), pp. 415—421. EAAP Publication No. 12. Oriel Press Ltd.

RIBEIRO, J.M. DE C.R., BROCKWAY, J.M. and WEBSTER, A.J.F. (1977). A note on the energy cost of walking in cattle. *Animal Production*, **25**, 107—110.

RICHARDS, J.I. and LAWRENCE, P.R. (1984). The estimation of energy expenditure from heart rate in working oxen and buffalo. *Journal of Agricultural Science* (Cambridge), **102**, 711—717.

RUBNER, M. (1894). Die quelle der thierischen wärme. *Zeitschrift für Biologie*, **30**, 73—142.

RUBNER, M. (1902). *The Laws of Energy Consumption in Nutrition*. English translation, 1982. Academic Press, New York.

RYAN, B.F., JOINER, B.L. and RYAN, T.A. (1985). *Minitab Handbook*. Second edition. PWS-Kent Publishing Company, Boston.

SAHLU, T., HART, S.P., KLEIN, P.D., JACQUEMET, N. and CARNEIRO, H. (1992). Application of $^{13}CO_2$ measurements to the estimation of energy expenditure in goats. *Canadian Journal of Animal Science*, **72**, 245—252

SCHOELLER, D.A. and VAN SANTEN, E. (1982). Measurement of energy expenditure in humans by doubly labelled water method. *Journal of Applied Physiology*, **53**, 955—959.

SCHOELLER, D.A. and WEBB, P. (1984). Five-day comparison of the doubly labelled water method with respiratory gas exchange. *The American Journal of Clinical Nutrition*, **40**, 153—158.

SMITH, A.J. (1981a). Draught animal research. A neglected subject. *World Animal Review*, **40**, 41—48.

SMITH, A.J. (1981b). Role of draught animals in agricultural systems in developing countries. In: *Vegetable Productivity* (Ed. C.R.W. Spedding), pp. 247—262. Macmillan Publishers Ltd., London.

SNEDDON, J.C. (1986). The effect of treadmill slope on the relationship between heart rate and energy expenditure in cattle walking on treadmills. *Journal of Agricultural Science* (Cambridge), **106**, 433—436.

SNEDDON, J.C., MATHERS, J.C. and THOMSON, C.J. (1985). Prediction of energy expenditure from heart rate measurements in exercising cattle. *Proceedings of the Nutrition Society*, **44**, 33A.

STARKEY, P.H. (1981). *Farming with Work Oxen in Sierra Leone.* Sierra Leone Work Oxen Project, Njala University, Freetown.

STARKEY, P.H., SIRAK TEKLU and GOE, M.R. (1991). *Animal Traction. An Annotated Bibliographic Database.* ILCA, Addis Ababa.

TAYLOR, C.R., SCHMIDT-NIELSEN, K. and RAAB, J.L. (1970). Scalling of energetic cost of running to body size in mammals. *American Journal of Physiology*, **219**, 1104—1107.

TELENI, E. and HOGAN, J.P. (1989). Nutrition of draught animals. In: *Draught Animals in Rural Development.* (Eds. D. Hoffman, J. Nari, and R.J. Petheram), pp. 118—133. ACIAR Proceedings Series No. 27.

TELENI, E. and PIETERSON, R. (1989). As reported by Teleni, E. and Hogan, J.P. (1989). Nutrition of draught animals. In: *Draught Animals in Rural Development* (Eds. D. Hoffman, J. Nari and R.J. Petheram), pp. 118—133. ACIAR Proceedings Series No. 27.

THOMAS, C. K. and PEARSON, R.A. (1986). Effect of head cooling on energy expenditure, feed intake and heat tolerance of Brahman and Brahman x Friesian cattle working on treadmills. *Animal Production*, **43**, 83—90.

TUCKER, V. A. (1969). Energetic cost of locomotion in animals. *Comparative Biochemistry and Physiology*, **34**, 841—846.

UNIVERSITY OF FLORIDA (1974). *Latin American Tables of Feed Composition*. Department of Animal Science, University of Florida, Gainesville, USA.

VERCOE, J.E. (1970a). Fasting metabolism and heat increment of Brahman x British and British cattle. In: *Energy Metabolism of Farm Animals* (Eds. A. Schurch and C. Wenk), pp. 85—88. EAAP Pubilcation No. 13, Juris, Zurich.

VERCOE, J.E. (1970b). The fasting metabolism of Brahman, Africander and Hereford x Shorthorn cattle. *British Journal of Nutrition*, **24**, 599—606.

WARDA (1988). *Annual Report*. Bouaké, Ivory Coast.

WEBB, P., ANNIS, J.F. and TROUTMAN, S.J. (1972). Human calorimetry with a water-cooled garment. *Journal of Applied Physiology*, **32**, 412—418.

WEBB, P. and TROUTMAN, S.J. (1970). An instrument for continuous measurement of oxygen consumption. *Journal of Applied Physiology*, **28**, 867—871.

WEBSTER, A.J.F. (1967). Continuous measurement of heart rate as an indicator of the energy expenditure of sheep. *British Journal of Nutrition*, **21**, 769—785.

WEIR, J.B. de V. (1949). New methods of calculating metabolic rate with special reference to protein metabolism. *Journal of Physiology*, **109**, 1—9.

WHITE, R.G. and LENG, R.A. (1968). Carbon dioxide entry rate as an index of energy expenditure in lambs. In: *Proceedings of the Australian Society for Animal Production* (Ed. J.L. Corbett), **7**, 335—341.

WHITE, R.G. and YOUSEF, M.K. (1978). Energy expenditure in reindeer walking on roads and on tundra. *Canadian Journal of Zoology*, **56**, 215—223.

WHITELAW, F.G. (1974). Measurement of energy expenditure in the grazing ruminant. *Proceedings of the Nutrition Society*, **33**, 163—171.

WHITELAW, F.G., BROCKWAY, J.M. and REID, R.S. (1972). Measurement of carbon dioxide production in sheep by isotope dilution. *Quarterly Journal of Experimental Physiology*, **57**, 37—55.

YAMAMOTO, S., McLEAN, J.A. and DOWNIE, A.J. (1979). Estimation of heat production from heart rate measurements in cattle. *British Journal of Nutrition*, **42**, 507—513.

YOUNG, B.A. (1970). Application of the carbon dioxide entry rate technique in the measurement of energy expenditure by grazing cattle. In: *Proceedings of the Fifth Symposium on the Energy Metabolism of Farm Animals* (Eds. A. Schurch and C. Wenk), pp. 237—241. EAAP Publication No. 13. Juris and Verlag, Zurich.

YOUNG, B.A., LENG, R.A., WHITE, R.G., McCLYMONT, G.L. and CORBETT, J.L. (1969). Estimation of energy expenditure from measurement of carbon dioxide entry rate. In: *Proceedings of the Fourth Symposium on the Energy Metabolism of Farm Animals* (Eds. K.L. Blaxter, J. Kielanowski and G. Thorbeck), pp. 435—436. EAAP Publication No. 12. Oriel Press Ltd.

YOUNG, B.A. and WEBSTER, M.E.D. (1963). A technique for the estimation of energy expenditure in sheep. *Australian Journal of Agricultural Research*, **14**, 867—873.

ZERBINI, E., GEMEDA, D.H., O'NEILL, D.H., HOWELL, P.J. and SCHROTER, R.C. (1992). Relationships between cardio-respiratory parameters and draught work output in F1 crossbred dairy cows under field conditions. *Animal Production*, **55**, 1—10.

ZUNTZ, N., LOEWY, A., MULLER, F. and CASPARI, W. (1906). *Hohenklima und Bergwanderungen*. Deutsches Verlagshaus Bong and Co., Berlin.

APPENDICES

1 — 17

APPENDIX 1

Facemask manufacture.

BASIC MASK CONSTRUCTION

Materials:
— Plywood, good quality 10 mm ply
— Wood glue
— Selection of 5 mm bolts
— Hammerite paint, to seal wood against moisture

Wood cutting list

Mask body

Front panel		two of 104.5[1] mm	(45°x 67.5°) x 150[1] mm
Side panel		two of 120 mm	(67.5° x 67.5°) x 150 mm
Back	—	two of 55 mm	(67.5° x 67.5°) x 150 mm
Centre back	—	one of 70 mm	(67.5° x 67.5°) x 150 mm
Harness anchor	—	two of 50 mm x 105 mm	
Spacer	—	two of 50 mm x 50 mm	

[1] All mask panel sizes obviously vary with different face sizes of the animals.

Machining

Front panels:	—	hole 70 mm diameter (minimum), top edge of hole approximately 85 mm from top of the panel. Six bolt holes (Plate 13).
Centre back:	—	hole 30 mm diameter (minimum), top edge of hole approximately 100 mm from top of the panel. Six bolt holes.
Harness anchors:	—	horizontal slit (30 mm x 5 mm) to allow harness attachment. Round off the corners for safety.
Side panels/Harness anchors/: Spacers	—	drill one bolt hole to attach all three together.

PLATE 13

Facemask panels.

PLATE 14

Putting the wooden outershell together.

Assembly

1. Complete all the machining.

2. Lay out two parallel strips of sticky tape, sticky surface uppermost.

3. Place the panels edge-to-edge, outer surface down, in order along the tape.

4. Assemble mask with the use of the sticky tape and check that edges join properly.

5. Lay the panels out flat again and apply wood glue to the edges. Reassemble as before and leave it taped firmly together until set (Plate 14).

6. Apply wood glue to the spacers and harness attachments and to the side panels before clamping them together (Plate 15).

7. Smooth off all rough edges, especially at the top and bottom of all panels since this is where the latex sleeves will rub and possibly tear.

8. Paint the whole mask, every nook and cranny, with water repellant paint. Apply one more coat than you think is needed because if any water/condensation gets into the plywood the mask may fall apart (Plate 16).

9. Strong elastic, as used by saddlers should be used in joining a clip/snap to the mask, since it gives a little and keeps the mask fitting securely yet comfortably.

AIRTIGHT SEALS

Materials

— Latex rubber sheeting, 0.5 mm thick and 1.0 mm thick

— Templates (Figure 17)

— Scissors, sharp

— Double-sided sticky tape

— Glue, of a type which will bond rubber to rubber giving a flexible joint. (In this case Bostik 3851 was used.)

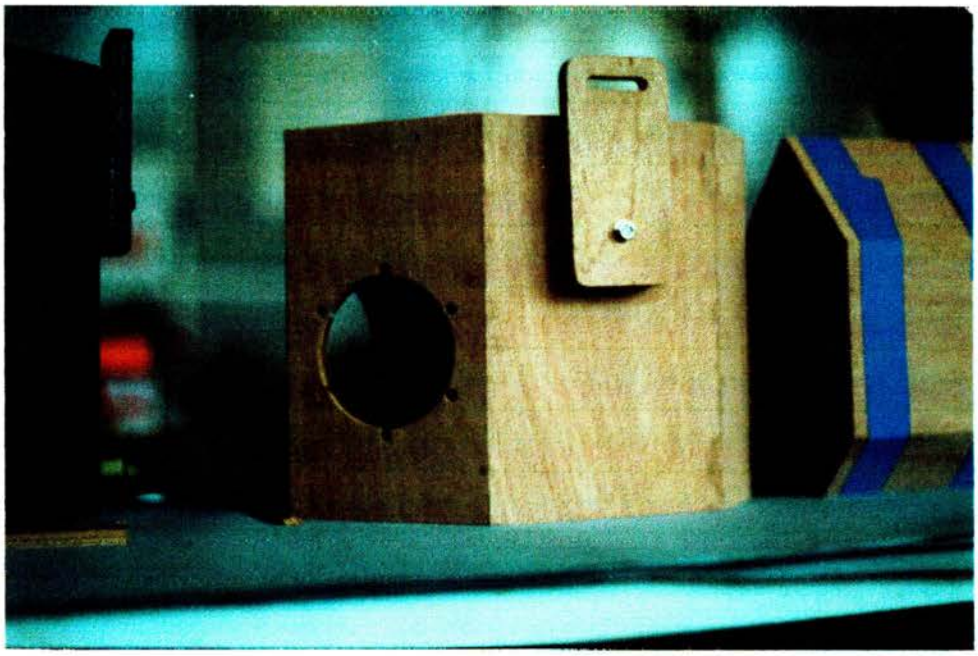


PLATE 15

Spacers and harness attachments.

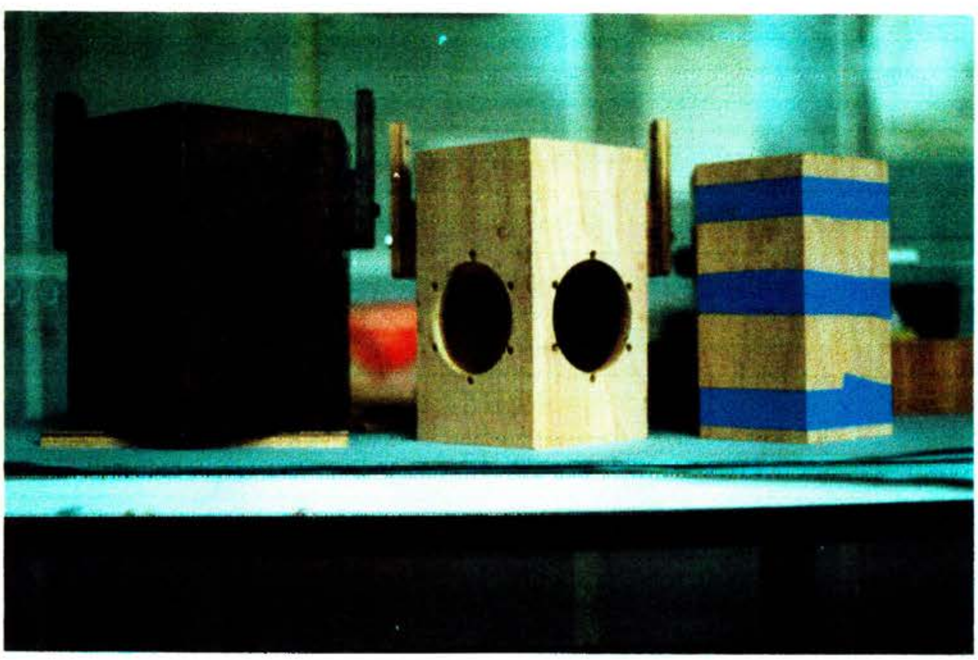


PLATE 16

The three stages in finishing the wooden outershell of the facemask.

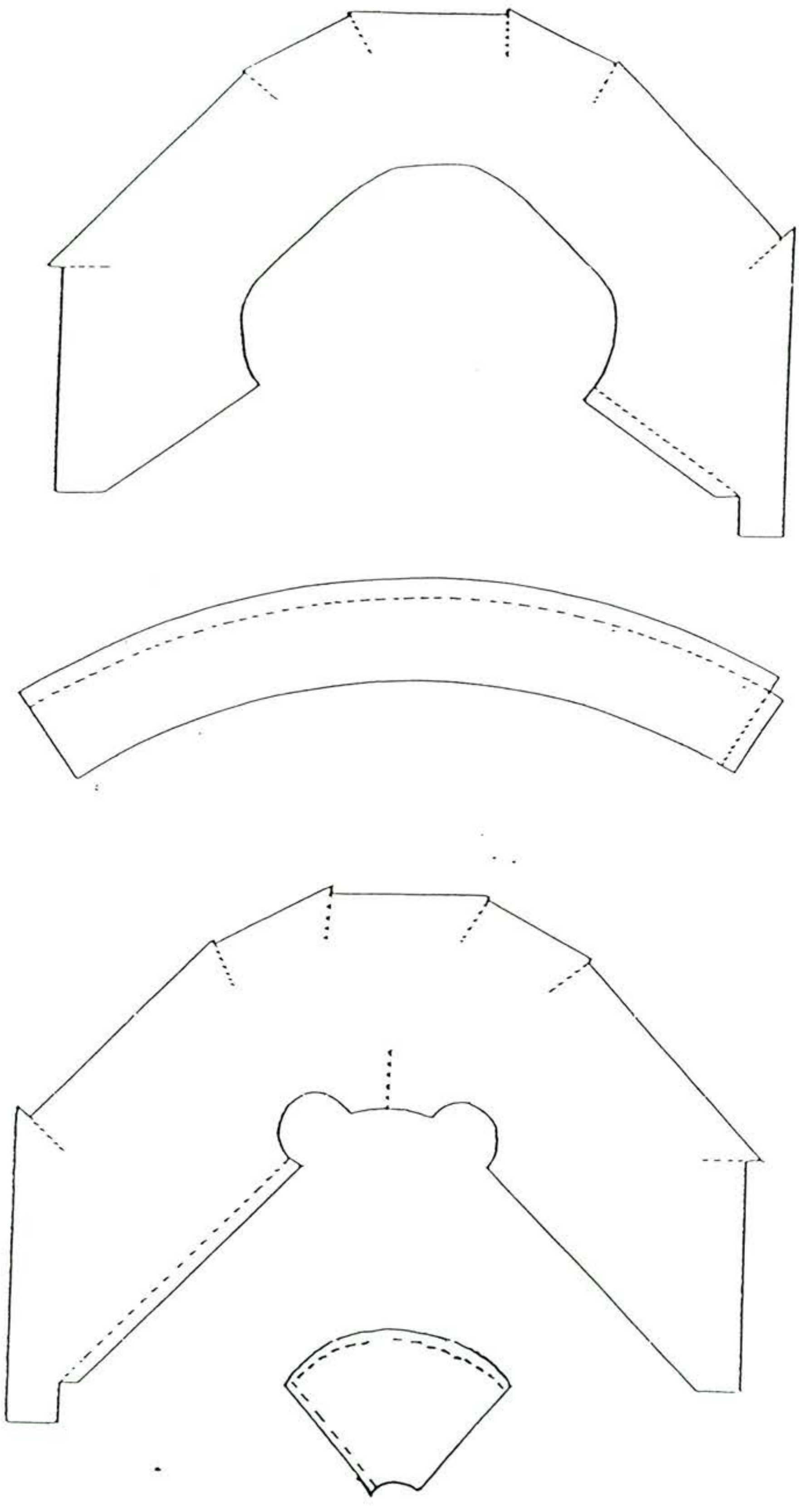


FIGURE 17

Templates for the tracing of the airtight seals for the Oxylog facemask.

Assembly

Face/mask seal (0.5 mm latex)

1. Trace the sleeve and cuff templates onto the rubber and cut out accurately, any rough edges will tear under very slight pressure.

2. Refer to Plate 17. Put two strips of double-sided tape onto a bench. Place the shortest edge of both pieces along the tape so that they are held straight, but not stretched. The idea is that the surfaces to be glued are held in a straight line making the job more easy. In practice the sticky tape tends to get a good hold on the latex and can make it difficult to remove the bonded latex without tearing it. A hint is to rub the tape with a friable cloth to reduce its adhesive strength.

3. Apply the glue according to the manufacturers instructions.

4. Lift the cuff by removing the tape from the bench, this will make it more easy to handle, and apply to the sleeve edge.

5. When the glue has bonded remove the tape from the cuff and the complete sleeve from the bench.

6. Glue the ends of the latex together to form a sleeve. The technique described in 2, 3 and 4 is possible but a wine bottle may be easier to form the sleeve around than a flat bench (Plate 18).

7. as in 5.

8. Using the top of the mask as your guide, glue the mitred corners of the sleeve so that they grip the top orifice.

9. Once complete the sleeve should slip over the face end of the mask and stay there. It is secured in position using electrical tape on the outer surface of the mask. The back edge of the top of the mask tends to rub against the jaw bones, so some padding is advisable between the latex and the plywood.

Nose/mask seal (0.5 mm latex)

1. As in 1 to 8, using the appropriate template.

2. Fit and secure as in 9 but without any padding.

Seal for holes in front and centre back panels (1.0 mm latex)

1. Draw around the inner and outer edges of the valve and spit trap holders. Cut around these lines and punch holes for the bolts to pass through. Now fit the valve holders and spit trap in their place.

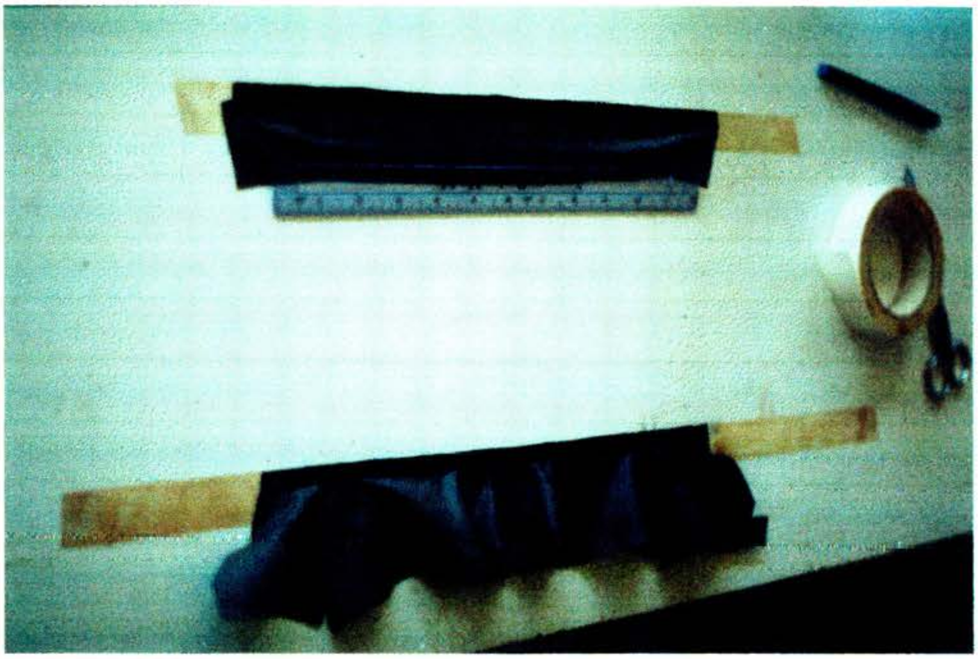


PLATE 17

Applying the latex glue to the latex.

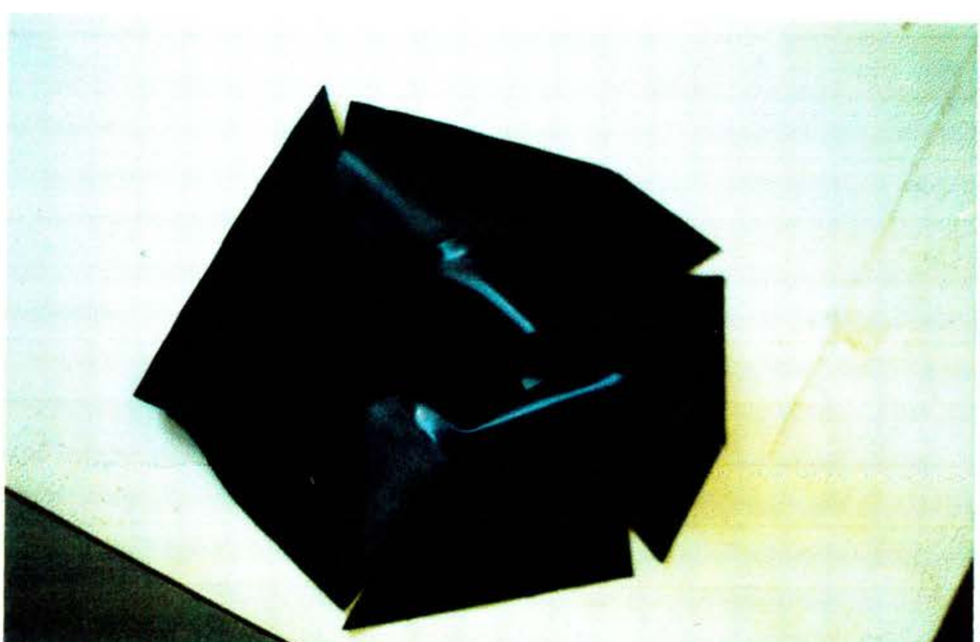
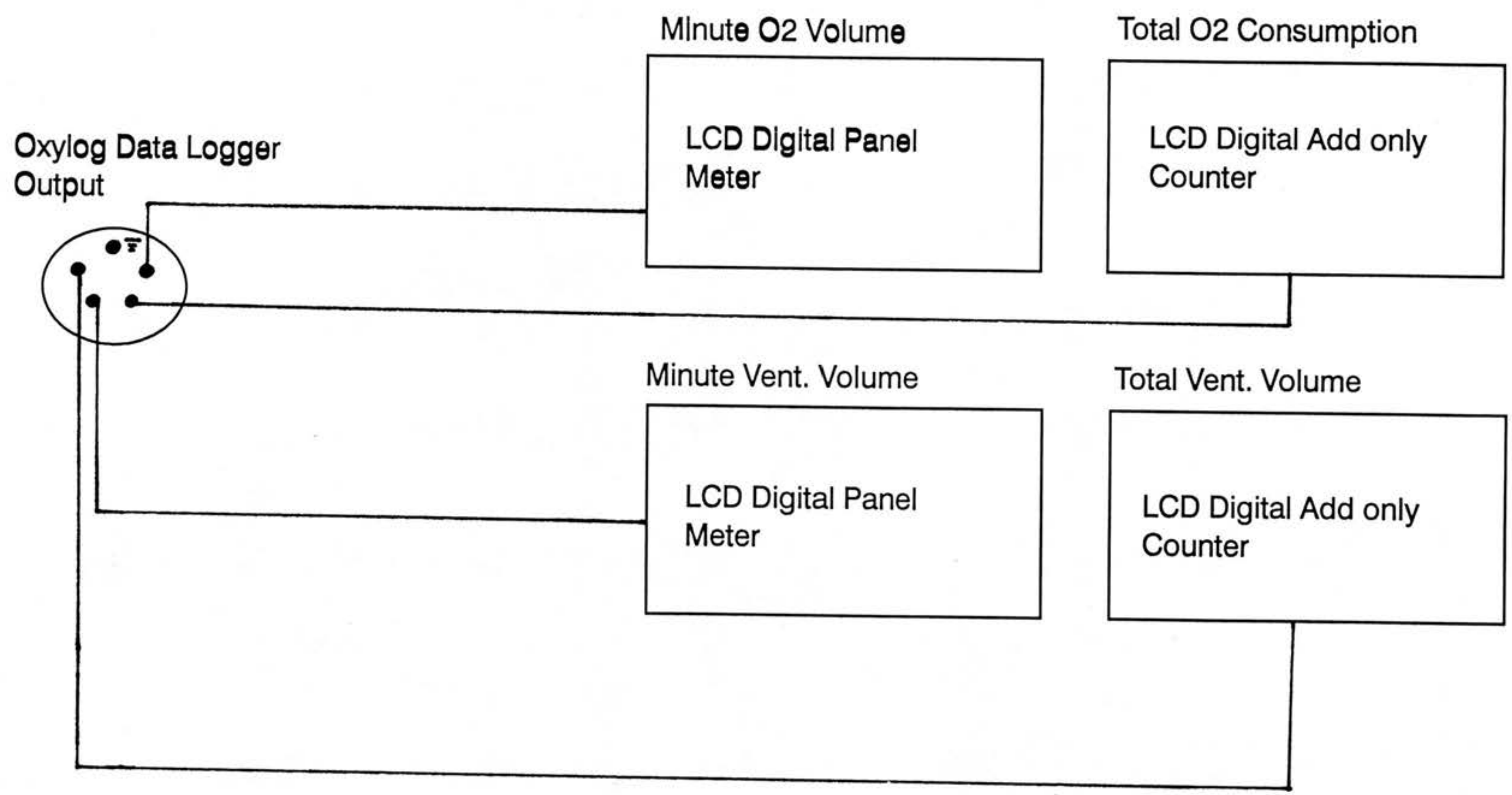


PLATE 18

Forming the annular cuff.

143a.

Diagram of Data viewer connections



APPENDIX 2

Experimental results of the validation trial.

Period	Gas analysis O_2 measurement (std. l)	Oxylog O_2 measurement (std. l)	% difference	minutes	Oxylog ventilation volume (std. l)
9	60.1	56.4	6.2	16	1907.6
7	59.3	53.9	9.1	13	1643.7
1	58.1	61.5	-5.7	15	2028.3
3	58.1	56.8	2.3	16.5	1813.4
3	57.5	53.5	7.0	13	1594.7
4	55.6	50.1	9.8	12.5	1658.8
1	55.4	58.0	-4.7	15	1775.7
11	54.7	53.0	3.1	13	1594.7
2	54.6	48.5	11.0	19.5	2005.6
11	54.0	53.9	0.2	14.8	1805.8
1	53.5	58.0	-8.5	16	1606.0
3	53.2	53.5	-0.6	14.5	1689.0
1	52.9	52.2	1.1	15	1738.0
3	52.7	44.3	16.0	14	1377.0
6	52.0	49.7	4.4	15	1421.3
4	51.9	53.4	-2.8	13	1585.9
4	50.4	43.0	14.7	26.5	1751.4
7	49.8	39.5	20.6	23	1451.5
10	49.7	42.2	15.1	31	1489.2
12	49.5	46.6	5.7	13	1519.3
12	49.2	45.3	8.0	17	1719.1
6	49.2	48.8	0.9	13	1440.1
4	49.1	45.9	6.5	13	1628.6
5	49.0	44.2	9.9	14.5	1413.8
5	48.6	46.7	3.9	11	1425.1
2	48.3	50.4	-4.4	12.5	1447.7
6	48.1	46.7	2.9	12.5	1353.4
13	47.9	43.6	9.1	12	1278.0
12	47.0	46.7	0.6	13	1519.3
8	46.8	49.6	-5.9	12	1493.0
2	46.7	38.4	17.9	12	1564.6
10	46.5	49.2	-5.7	12	1379.8
9	46.4	48.0	-3.5	20.5	2005.6
2	46.3	47.6	-2.9	13	1406.2
10	46.3	46.3	0.0	12	1523.1
5	46.2	45.0	2.7	14	1425.1
7	46.2	51.5	-11.5	15	1575.9
5	46.0	50.4	-9.6	12.5	1447.7
2	45.7	50.0	-9.4	15	1794.5
1	45.5	47.9	-5.2	13	1436.4
9	45.4	48.8	-7.6	15	1474.1
10	44.7	45.0	-0.7	15	1406.2
11	44.5	37.9	14.9	20.5	1353.4

Continued

Period	Gas analysis O_2 measurement (std. l)	Oxylog O_2 measurement (std. l)	% difference	minutes	Oxylog ventilation volume (std. l)
10	44.1	43.3	1.9	12	1278.0
13	44.0	41.1	6.6	11.5	1278.0
10	43.9	42.1	4.1	16.5	1481.6
2	43.9	41.3	5.8	24	1259.2
8	43.7	47.1	-7.8	12	1391.1
9	42.9	47.5	-10.8	16.5	1568.3
14	42.9	42.4	1.1	15	1293.1
10	42.2	43.4	-2.9	11.5	1394.9
7	42.0	44.2	-5.2	14.5	1470.3
3	41.7	42.1	-0.8	11	1391.1
14	40.9	43.0	-5.1	13	1300.7
13	39.5	43.5	-9.9	11.5	1394.9
4	37.8	38.7	-2.4	11.5	1161.2
10	37.2	41.2	-10.7	11.5	1278.0
8	37.0	40.4	-9.2	10.5	1281.8

* *Example of a paired t-test on Minitab of experimental results of the Oxylog validation trial.*

C_3 = 'difference'
let 'difference' = 'Oxylog' - 'Open circuit'
t-test 0 'difference'

TEST of MU = 0.000 vs MU NE 0.000

	n	mean	SD*	S.E. mean	T	P value
'difference'	58	-0.75	3.84	0.50	-1.48	0.14

*SD = standard deviation

APPENDIX 3

Experimental results during the Colombian field trial.

Buffalo No. 1	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	1.3	1.1	0.4	0.5
Total distance (m)	2676	2293	1246	1687
Total EWT (min)	46	39	23	32
SMR (24 h)	43	56	54	54
Mask period (h)	2.5	2	2	2.5
Work done (MJ)	0.6	0.45	0.1	0.3
Distance (m)	1563	1125	326	1245
EWT (min)	25	20	5	19
O_2 consumption (l)	468.6	415.5	256	415
Efficiency of doing work (%)	23	19	26	21

Buffalo No. 2	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	0.4	0.4	0.7	0.9
Total distance (m)	1293	622	2757	2444
Total EWT (min)	25	19	42	61
SMR (24 h)	53	53	58	56
Mask period (h)	3	2	2	2
Work done (MJ)	0.3	0.1	0.55	0.35
Distance (m)	823	237	1811	893
EWT (min)	16	6	30	24
O_2 consumption (l)	449.3	260.9	517	367
Efficiency of doing work (%)	24	17	19	26

Buffalo No. 3	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	1.4	1.2	1	0.5
Total distance (m)	3404	3129	1197	1918
Total EWT (min)	67	73	26	37
SMR (24 h)	53	50	57	57
Mask period (h)	3	2	2.5	2
Work done (MJ)	0.95	0.45	0.65	0.2
Distance (m)	2742	1237	453	671
EWT (min)	41	32	11	14
O_2 consumption (l)	734	358	507	326
Efficiency of doing work (%)	22	27	17	19

Continued

Buffalo No. 4	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	0.75	0.3	0.6	0.3
Total distance (m)	2830	1064	2992	756
Total EWT (min)	na	19	56	26
SMR (24 h)	67	64	64	67
Mask period (h)	2	1.5	1	1
Work done (MJ)	0.35	0.1	0.15	0.05
Distance (m)	1237	321	637	169
EWT (min)	na	5	12	5
O_2 consumption (l)	454	237	193.3	159.4
Efficiency of doing work (%)	21	19	25	19

Buffalo No. 5	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	0.7	0.2	0.6	0.4
Total distance (m)	2212	738	1908	1274
Total EWT (min)	na	23	54	46
SMR (24 h)	68	63	67	65
Mask period (h)	2	2	1.5	2
Work done (MJ)	0.35	0.12	0.28	0.1
Distance (m)	981	415	627	429
EWT (min)	na	15	18	13
O_2 consumption (l)	410.6	314.5	304.3	323.7
Efficiency of doing work (%)	30	21	26	17

Buffalo No. 6	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	0.8	0.7	0.8	0.4
Total distance (m)	3153	1677	1912	1360
Total EWT (min)	69	43	na	29
SMR (24 h)	61	54	59	62
Mask period (h)	2	2	2	2
Work done (MJ)	0.4	0.15	0.35	0.15
Distance (m)	1710	537	767	401
EWT (min)	34	16	na	10
O_2 consumption (l)	445.9	287.4	357.5	316
Efficiency of doing work (%)	28	23	27	20

Continued

Ox No. 1	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	0.5	0.5	0.7	0.2
Total distance (m)	1565	1395	2657	851
Total EWT (min)	37	39	54	21
SMR (24 h)	49	53	51	53
Mask period (h)	2.5	2.5	2	2
Work done (MJ)	0.3	0.25	0.2	0.05
Distance (m)	721	637	917	211
EWT (min)	19	15	18	6
O_2 consumption (l)	382.9	388.4	309.2	241
Efficiency of doing work (%)	16	15	21	16

Ox No. 2	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	0.6	0.7	0.2	0.5
Total distance (m)	2530	2360	595	1509
Total EWT (min)	48	41	18	34
SMR (24 h)	57	40	58	43
Mask period (h)	2	2	2	3
Work done (MJ)	0.25	0.3	0.07	0.35
Distance (m)	714	829	127	973
EWT (min)	12	15	4	23
O_2 consumption (l)	345.4	280.2	262.3	424.9
Efficiency of doing work (%)	17	20	15	16

Ox No. 3	DAY1	DAY2	DAY3	DAY4
Total work done (MJ)	0.45	0.8	0.3	0.7
Total distance (m)	1463	2872	893	1962
Total EWT (min)	35	65	19	44
SMR (24 h)	56	67	67	69
Mask period (h)	2	2	1.5	1
Work done (MJ)	0.1	0.35	0.05	0.25
Distance (m)	479	1189	251	743
EWT (min)	12	25	5	18
O_2 consumption (l)	282.6	439.6	235.9	245.2
Efficiency of doing work (%)	22	20	16	23

Continued

* Example of two sample T-test on Minitab for efficiency of doing work of buffaloes and oxen working in an oil-palm plantation in Colombia.

Two sample -t efficiency of buffaloes (A) efficiency of oxen (B)

	n	mean	SD	SE mean
A	24	22.3	3.83	0.78
B	12	18.1	2.91	0.84

95 PCT CI for MU A - MU B: (1.90, 6.60)

T-test MU A = MU B (US ME): T = 3.71 P = 0.0009 DF = 28

APPENDIX 4

Ventilation volumes, resting and mask periods during the Colombian trial.

Buffalo No. 1	DAY1	DAY2	DAY3	DAY4
Mask period (h)	2.5	2	2	2.5
Ventilation volume (l)	19452.3	17540	14327.9	21889
Resting ventilation volume (l/min/kg$^{0.73}$)	0.73	0.68	0.91	0.78

Buffalo No. 2	DAY1	DAY2	DAY3	DAY4
Mask period (h)	3	2	2	2
Ventilation volume (l)	22933.7	13130.2	17767.7	18700
Resting ventilation volume (l/min/kg$^{0.73}$)	0.53	0.74	0.61	0.59

Buffalo No. 3	DAY1	DAY2	DAY3	DAY4
Mask period (h)	3	2	2.5	2
Ventilation volume (l)	29818.8	18914.5	24289.7	17895.4
Resting ventilation volume (l/min/kg$^{0.73}$)	0.81	0.70	0.85	0.95

Buffalo No. 4	DAY1	DAY2	DAY3	DAY4
Mask period (h)	2	1.5	1	1
Ventilation volume (l)	16965	13943.7	11641	9363.9
Resting ventilation volume (l/min/kg$^{0.73}$)	0.55	0.73	0.65	0.82

Buffalo No. 5	DAY1	DAY2	DAY3	DAY4
Mask period (h)	2	2	1.5	2
Ventilation volume (l)	21826	18278.1	16753.1	17363.1
Resting ventilation volume (l/min/kg$^{0.73}$)	0.95	0.77	0.83	0.71

Buffalo No. 6	DAY1	DAY2	DAY3	DAY4
Mask period (h)	2	2	2	2
Ventilation volume (l)	18367.8	12669.8	16422.9	14007.4
Resting ventilation volume (l/min/kg$^{0.73}$)	0.63	0.59	0.68	0.84

Continued

Ox No. 1	DAY1	DAY2	DAY3	DAY4
Mask period (h)	2.5	2.5	2	2
Ventilation volume (l)	22047.3	20729.3	18689.8	12437.2
Resting ventilation volume (l/min/kg$^{0.73}$)	0.58	0.64	0.67	0.81

Ox No. 2	DAY1	DAY2	DAY3	DAY4
Mask period (h)	2	2	2	3
Ventilation volume (l)	15620.9	15356	14044	24918.6
Resting ventilation volume (l/min/kg$^{0.73}$)	0.67	0.57	0.81	0.64

Ox No. 3	DAY1	DAY2	DAY3	DAY4
Mask period (h)	2	2	1.5	1
Ventilation volume (l)	16190.6	18769.7	13027.6	14775.4
Resting ventilation volume (l/min/kg$^{0.73}$)	0.83	0.83	0.71	0.75

APPENDIX 5

SMR (MJ/day) as calculated with the Oxylog measurments and the calculated ME maintenance requirements (MAFF, 1984), and extra energy expended during work during the mask periods, as measured by the Oxylog and as calculated by a factorial method (Lawrence, 1985) during the Colombian field trial.

Work done during mask period (MJ)	Distance walked during mask period (m)	Body weight	SMR (MJ/day) Oxylog	ME (MJ/day) MAFF	Energy expended during work (MJ) during mask periods 'Factorial method'	Oxylog
0.60	1563	625	43	63.74	4.05	5.22
0.45	1125	625	56	63.74	2.98	3.93
0.10	326	625	54	63.74	0.76	0.80
0.30	1245	625	54	63.74	2.63	2.97
0.30	823	805	53	76.68	2.39	2.68
0.10	237	805	53	76.68	0.73	0.98
0.55	1811	805	58	76.68	4.89	5.87
0.35	893	805	56	76.68	2.68	2.93
0.95	2742	750	53	72.82	7.49	8.57
0.45	1237	750	50	72.82	3.45	3.24
0.65	453	750	57	72.82	2.88	4.56
0.20	671	750	57	72.82	1.72	2.00
0.35	1237	650	67	65.59	2.86	3.81
0.10	321	650	64	65.59	0.77	0.91
0.15	637	650	64	65.59	1.37	1.33
0.05	169	650	67	65.59	0.40	0.51
0.35	981	760	68	73.52	2.73	2.83
0.12	415	760	63	73.52	1.06	1.26
0.28	627	760	67	73.52	1.93	2.11
0.10	429	760	65	73.52	1.02	1.28
0.40	1710	740	61	72.10	3.99	4.15
0.15	537	740	54	72.10	1.33	1.45
0.35	767	740	59	72.10	2.36	2.48
0.15	401	740	62	72.10	1.12	1.37
0.30	721	625	49	63.74	1.95	2.82
0.25	637	625	53	63.74	1.67	2.52
0.20	917	625	51	63.74	1.87	2.15
0.05	211	625	53	63.74	0.44	0.57
0.25	714	600	57	61.87	1.73	2.40
0.30	829	600	40	61.87	2.04	2.47
0.07	127	600	58	61.87	0.39	0.60
0.35	973	600	43	61.87	2.39	3.42
0.10	479	700	56	69.24	1.04	1.18
0.35	1189	700	67	69.42	2.91	3.52
0.05	251	700	67	69.24	0.54	0.70
0.25	743	700	69	69.24	1.93	2.20

APPENDIX 6

Calculation of DMI during the Colombian field trial.

Average weight of the animals	= 695 kg
	= 118.75 $kg^{0.73}$
SMR = 118.75 x 0.016 x 60 x 24 x 20.7	= 57.4 MJ/day
Animals work at 1.08 times SMR	= 62 MJ/day
q (metabolisability) = 0.5	
ME content of the diet	= 9.35 MJ ME/kgDM
DMI needed	= 6.6 kg

Possible intake:

$$DMI - g/kg^{0.73} = 106.5q + 24.1 \quad = 77.4\ g/kg^{0.73}$$

$$= 9.2\ kg\ DMI/day$$

Possible intake taking the molasses fed into account:

$$DMI - g/kg^{0.73} = 106.5q + 37p + 24.1 =$$

p = proportion of concentrate in the diet

DMI molasses, 760 g per animal per day (Table 7) = 6.4 $g/kg^{0.73}$

Let DMI = X

$$X = 106.5 \times 0.5 + 37 \times 6.4/X + 24.1 \quad = 80.0\ g/kg^{0.73}$$

$$= 9.5\ kg\ DMI/day$$

Formulas from MAFF (1984)

APPENDIX 7

Calculation of the protein requirements and intake by animals during the Colombian trial.

Average weight of the animals	= 695 kg = 135.4 $kg^{0.75}$
Tissue protein needs	= 2.188 $g/W^{0.75}$ (endogenous protein requirements)
	= 0.113 $g/W^{0.75}$ (dermal losses)
Total tissue protein needs	= 311 g
Efficiency of amino acid utilisation	= 0.85
Total protein to be supplied to tissues to meet the needs	= 366 g

On the described diet **9 g** of microbial protein could be synthesised by the rumen microbes **per MJ ME**. Hence, on the DMI estimated in section 5.6, **774 g** of microbial protein could be synthesised.

774 g of microbial protein synthesised requires an intake of 815 g of RDP (774/0.95)

CP intake = 1419.1 g of which between 60 to 80 % was estimated to be RDP.(851.5 - 1135.3 g RDP)

Total microbial protein synthesised	= 774 g
Total protein supplied to the tissues	= 774 x 0.80 x 0.85 = 526 g

Factors and formulas from MAFF (1989) and ADAS (1991)

APPENDIX 8

Ventilation volumes (l/min/kg$^{0.73}$) of Bunaji draught bulls during various experimental activities in the sub-humid zone of Nigeria.

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume (l/min/kg$^{0.73}$)
398	R	320	67.4	1.16
398	R	320	67.4	1.01
397	R	300	64.3	1.08
397	R	300	64.3	0.95
111	R	370	75.0	1.15
111	R	370	75.0	1.17
113	R	395	78.6	1.12
113	R	395	78.6	1.24
112	R	315	66.6	1.29
112	R	315	66.6	0.92
114	R	390	77.9	1.18
114	R	390	77.9	1.28
663	R	410	80.8	0.95
663	R	410	80.8	1.04
663	R	410	80.8	1.18
663	R	410	80.8	1.47
770	R	355	72.7	1.13
770	R	355	72.7	1.17
111	R	375	75.7	1.21
114	R	380	76.4	1.03
112	R	325	68.2	0.94
112	R	325	68.2	1.30
112	R	325	68.2	0.82
112	R	325	68.2	0.88
113	R	390	77.9	0.91
113	R	390	77.9	1.20
111	R	385	77.2	0.79
111	R	385	77.2	0.85
111	R	385	77.2	1.01
398	R	310	65.9	0.67
398	R	310	65.9	0.87
397	R	335	69.7	1.12
397	R	330	68.9	0.95
397	R	330	68.9	1.39
663	R	390	77.9	1.23
663	R	390	77.9	1.28
111	R	375	75.7	1.25
111	R	375	75.7	1.55
113	R	385	77.2	0.85
113	R	385	77.2	1.10
114	R	380	76.4	1.33
114	R	380	76.4	1.13
112	R	310	65.9	1.19
112	R	310	65.9	1.51
398	R	340	70.5	0.85

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume ($l/min/kg^{0.73}$)
398	R	340	70.5	0.95
397	R	345	71.2	0.88
397	R	345	71.2	1.10
113	R	413	81.2	0.80
113	R	413	81.2	1.18
113	R	413	81.2	0.98
113	R	413	81.2	1.02
113	R	413	81.2	1.42
111	R	405	80.1	0.84
111	R	405	80.1	1.11
114	R	430	83.6	1.26
398	R	345	71.2	0.95
398	R	345	71.2	1.06
397	R	380	76.4	0.72
397	R	380	76.4	0.99
397	R	365	74.2	0.95
397	R	365	74.2	1.77
112	R	340	70.5	1.09
112	R	340	70.5	0.95
112	R	350	72.0	0.65
112	R	350	72.0	0.90
112	R	350	72.0	0.66
112	R	350	72.0	0.84
114	R	395	78.6	0.99
114	R	395	78.6	1.61
113	R	435	84.4	0.97
113	R	435	84.4	0.99
113	R	440	85.1	1.05
113	R	440	85.1	1.16
111	R	430	83.6	0.97
111	R	430	83.6	1.01
398	R	350	72.0	1.03
398	R	350	72.0	1.50
397	R	380	76.4	1.11
397	R	380	76.4	1.24
113	R	410	80.8	0.65
113	R	410	80.8	0.76
112	R	355	72.7	0.64
397	R	395	78.6	0.59
397	R	395	78.6	1.33
113	R	440	85.1	0.72
111	R	435	84.4	0.69
111	R	435	84.4	0.76
112	R	350	72.0	0.68
112	R	350	72.0	1.10

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume ($l/min/kg^{0.73}$)
114	R	405	80.1	0.58
114	R	405	80.1	0.95
397	R	375	75.7	0.65
397	R	375	75.7	0.90
398	R	330	68.9	0.64
398	R	330	68.9	0.63
112	R	345	71.2	0.89
112	R	345	71.2	0.99
114	R	400	79.3	0.67
114	R	400	79.3	1.01
112	R	350	72.0	0.68
114	R	350	72.0	1.07
113	R	440	85.1	1.05
113	R	440	85.1	1.15
113	R	440	85.1	0.85
111	R	430	83.6	0.79
397	R	375	75.7	0.76
398	WU	320	67.4	1.93
398	WU	320	67.4	1.97
398	WU	320	67.4	2.02
397	WU	300	64.3	1.76
397	WU	300	64.3	1.67
397	WU	300	64.3	1.72
111	WU	370	75.0	1.75
111	WU	370	75.0	1.98
111	WU	370	75.0	2.04
113	WU	395	78.6	2.30
113	WU	395	78.6	2.26
113	WU	395	78.6	2.31
112	WU	315	66.6	2.19
112	WU	315	66.6	2.30
112	WU	315	66.6	2.46
114	WU	390	77.9	2.18
114	WU	390	77.9	2.26
114	WU	390	77.9	2.25
663	WU	410	80.8	2.04
663	WU	410	80.8	2.18
663	WU	410	80.8	2.35
770	WU	355	72.7	2.15
770	WU	355	72.7	2.22
770	WU	355	72.7	2.32
111	WU	375	75.7	1.84
114	WU	380	76.4	1.67
114	WU	380	76.4	1.92

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume (l/min/$kg^{0.73}$)
112	WU	325	68.2	1.49
112	WU	325	68.2	2.11
111	WU	385	77.2	1.17
111	WU	385	77.2	1.28
111	WU	385	77.2	1.81
398	WU	310	65.9	1.60
398	WU	310	65.9	2.22
114	WU	380	76.4	2.57
114	WU	380	76.4	1.70
398	WU	340	70.5	1.48
398	WU	340	70.5	1.83
112	WPU	325	68.2	1.76
113	WPU	390	77.9	2.35
113	WPU	390	77.9	2.73
397	WPU	335	69.7	2.80
397	WPU	330	68.9	1.92
397	WPU	330	68.9	2.85
663	WPU	390	77.9	2.38
663	WPU	390	77.9	2.82
663	WPU	390	77.9	3.06
111	WPU	375	75.7	2.60
111	WPU	375	75.7	3.02
113	WPU	385	77.2	2.23
113	WPU	385	77.2	2.55
112	WPU	310	65.9	2.33
112	WPU	310	65.9	2.47
397	WPU	345	71.2	1.66
397	WPU	345	71.2	2.65
113	WDF	413	81.2	2.30
113	WDF	413	81.2	2.59
111	WDF	405	80.1	2.42
114	WDF	430	83.6	1.67
398	WDF	345	71.2	1.99
398	WDF	345	71.2	2.35
397	WDF	380	76.4	2.27
397	WDF	380	76.4	2.32
397	WDF	365	74.2	1.81
112	WDF	340	70.5	1.71
112	WDF	350	72.0	1.59
112	WDF	350	72.0	1.72
112	WDF	350	72.0	1.71

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume (l/min/kg$^{0.73}$)
113	WPDF	413	81.2	2.23
113	WPDF	413	81.2	2.60
111	WPDF	405	80.1	1.88
397	WPDF	365	74.2	3.05
397	WPDF	365	74.2	3.05
112	WPDF	340	70.5	2.22
112	WPDF	350	72.0	1.51
114	WPDF	395	78.6	1.89
114	WPDF	395	78.6	2.45
113	WPDF	435	84.4	2.47
113	WPDF	435	84.4	2.48
113	WPDF	440	85.1	2.91
113	WPDF	440	85.1	2.67
111	WPDF	430	83.6	2.35
111	WPDF	430	83.6	1.77
112	WWF	355	72.7	2.08
397	WWF	395	78.6	1.90
113	WWF	440	85.1	1.62
111	WWF	435	84.4	1.58
111	WWF	435	84.4	2.01
112	WWF	350	72.0	2.25
112	WWF	350	72.0	2.65
114	WWF	405	80.1	1.23
114	WWF	405	80.1	2.17
398	WWF	330	68.9	2.04
398	WWF	330	68.9	1.59
112	WWF	345	71.2	2.28
112	WWF	345	71.2	2.49
114	WWF	400	79.3	1.76
114	WWF	400	79.3	1.91
112	WWF	350	72.0	1.91
112	WWF	350	72.0	2.64
113	WWF	440	85.1	2.55
113	WWF	440	85.1	2.49
111	WPWF	435	84.4	2.86
111	WPWF	435	84.4	3.05
111	WPWF	435	84.4	3.56
111	WPWF	435	84.4	2.76
112	WPWF	350	72.0	2.78
112	WPWF	350	72.0	3.01
112	WPWF	350	72.0	2.49

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume (l/min/kg$^{0.73}$)
113	WPWF	440	85.1	2.89
113	WPWF	440	85.1	2.90
113	WPWF	440	85.1	2.60
398	WPWF	330	68.9	3.45
398	WPWF	330	68.9	2.65
398	WPWF	330	68.9	2.38
114	WPWF	405	80.1	2.24
114	WPWF	405	80.1	2.89
114	WPWF	405	80.1	2.57
397	WPWF	395	78.6	2.57
113	WPWF	440	85.1	2.86
113	WPWF	440	85.1	2.34
111	HU	375	75.7	3.31
111	HU	375	75.7	3.24
111	HU	375	75.7	3.23
113	HU	385	77.2	3.25
113	HU	385	77.2	3.26
113	HU	385	77.2	3.27
112	HU	310	65.9	3.16
112	HU	310	65.9	3.01
112	HU	310	65.9	3.05
398	HU	340	70.5	2.71
398	HU	340	70.5	3.24
398	HU	340	70.5	3.04
397	HU	345	71.2	3.14
397	HU	345	71.2	3.49
397	HU	345	71.2	3.66
114	HU	390	77.9	2.85
114	HU	390	77.9	3.43
114	HU	390	77.9	2.98
112	HDF	350	72.0	2.11
112	HDF	350	72.0	2.25
112	HDF	350	72.0	2.51
114	HDF	395	78.6	2.35
114	HDF	395	78.6	2.81
114	HDF	395	78.6	3.44
113	HDF	440	85.1	3.41
113	HDF	440	85.1	3.34
113	HDF	440	85.1	3.33
111	HDF	430	83.6	2.75
111	HDF	430	83.6	2.74
111	HDF	430	83.6	2.65

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume ($l/min/kg^{0.73}$)
398	HDF	350	72.0	3.34
398	HDF	350	72.0	3.52
398	HDF	350	72.0	3.56
397	HDF	380	76.4	2.73
397	HDF	380	76.4	2.77
397	HDF	380	76.4	2.11
398	HWF	330	68.9	3.26
398	HWF	330	68.9	3.23
398	HWF	330	68.9	2.93
112	HWF	345	71.2	2.81
112	HWF	345	71.2	3.50
112	HWF	345	71.2	3.54
114	HWF	400	79.3	2.54
114	HWF	400	79.3	2.53
114	HWF	400	79.3	2.49
112	HWF	350	72.0	2.89
112	HWF	350	72.0	3.10
112	HWF	350	72.0	3.16
113	HWF	440	85.1	2.75
113	HWF	440	85.1	2.89
113	HWF	440	85.1	2.90
111	HWF	430	83.6	1.98
397	HWF	375	75.7	2.20
397	HWF	375	75.7	3.20
114	PU	380	76.4	2.44
114	PU	380	76.4	1.80
114	PU	380	76.4	2.40
112	PU	325	68.2	2.06
112	PU	325	68.2	3.10
112	PU	325	68.2	2.37
112	PU	325	68.2	2.16
112	PU	325	68.2	2.22
113	PU	390	77.9	2.87
111	PU	385	77.2	3.28 *
111	PU	385	77.2	3.42 *
111	PU	385	77.2	4.00 *
398	PU	310	65.9	3.44 *
398	PU	310	65.9	3.58 *
398	PU	310	65.9	3.63 *
397	PU	335	69.7	1.99
397	PU	330	68.9	2.25
397	PU	330	68.9	2.53

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average ventilation volume ($l/min/kg^{0.73}$)
113	PDF	413	81.2	3.03
113	PDF	413	81.2	2.42
111	PDF	405	80.1	2.92
111	PDF	405	80.1	3.16 *
111	PDF	405	80.1	3.15 *
114	PDF	430	83.6	2.76
114	PDF	430	83.6	3.19 *
114	PDF	430	83.6	3.15 *
398	PDF	345	71.2	3.27 *
398	PDF	345	71.2	3.65 *
398	PDF	345	71.2	4.34 *
397	PDF	365	74.2	2.36
397	PDF	365	74.2	2.74
397	PDF	365	74.2	2.98
397	PDF	365	74.2	2.73
112	PDF	350	72.0	2.47
112	PDF	350	72.0	2.62
112	PDF	350	72.0	2.76
113	PWF	440	85.1	2.15
113	PWF	440	85.1	2.19
113	PWF	440	85.1	2.01
111	PWF	435	84.4	2.32
111	PWF	435	84.4	2.59
111	PWF	435	84.4	2.62
112	PWF	350	72.0	2.80
112	PWF	350	72.0	2.89
112	PWF	350	72.0	3.03
114	PWF	405	80.1	2.19
114	PWF	405	80.1	2.27
397	PWF	375	75.7	2.04
397	PWF	375	75.7	2.17
112	PWF	350	72.0	3.08 *
112	PWF	350	72.0	3.10 *
112	PWF	350	72.0	3.16 *
398	PWF	345	71.2	2.78
398	PWF	345	71.2	2.06

R — resting
WU — walking upland
WPU — walking ploughed upland
WDF — walking dry fadama
WPDF — walking ploughed dry fadama
WWF — walking wet fadama
WPWF — walking ploughed wet fadama
HU — harrowing upland
HDF — harrowing dry fadama
HWF — harrowing wet fadama
PU — ploughing upland
PDF — ploughing dry fadama
PWF — ploughing wet fadama
* — animal walked on land already ploughed

APPENDIX 9

O_2 consumption (l/min/kg$^{0.73}$) of Bunaji draught bulls during resting periods in the sub-humid zone of Nigeria.

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average O_2 consumption (l/min/kg$^{0.73}$)
398	R	320	67.4	0.029
398	R	320	67.4	0.024
397	R	300	64.3	0.027
397	R	300	64.3	0.025
111	R	370	75.0	0.029
111	R	370	75.0	0.027
113	R	395	78.6	0.024
113	R	395	78.6	0.027
112	R	315	66.6	0.032
112	R	315	66.6	0.022
114	R	390	77.9	0.023
114	R	390	77.9	0.023
663	R	410	80.8	0.022
663	R	410	80.8	0.021
663	R	410	80.8	0.023
663	R	410	80.8	0.023
770	R	355	72.7	0.022
770	R	355	72.7	0.019
111	R	375	75.7	0.033
114	R	380	76.4	0.019
112	R	325	68.2	0.024
112	R	325	68.2	0.023
112	R	325	68.2	0.022
112	R	325	68.2	0.021
113	R	390	77.9	0.025
113	R	390	77.9	0.023
111	R	385	77.2	0.021
111	R	385	77.2	0.024
111	R	385	77.2	0.022
398	R	310	65.9	0.022
398	R	310	65.9	0.022
397	R	335	69.7	0.025
397	R	330	68.9	0.025
397	R	330	68.9	0.024
663	R	390	77.9	0.021
663	R	390	77.9	0.021
111	R	375	75.7	0.021
111	R	375	75.7	0.023
113	R	385	77.2	0.021
113	R	385	77.2	0.025
114	R	380	76.4	0.033
114	R	380	76.4	0.024
112	R	310	65.9	0.031
112	R	310	65.9	0.027
398	R	340	70.5	0.022

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average O_2 consumption ($l/min/kg^{0.73}$)
398	R	340	70.5	0.021
397	R	345	71.2	0.024
397	R	345	71.2	0.022
113	R	413	81.2	0.021
113	R	413	81.2	0.020
113	R	413	81.2	0.021
113	R	413	81.2	0.025
113	R	413	81.2	0.024
111	R	405	80.1	0.021
111	R	405	80.1	0.019
114	R	430	83.6	0.020
398	R	345	71.2	0.024
398	R	345	71.2	0.024
397	R	380	76.4	0.022
397	R	380	76.4	0.018
397	R	365	74.2	0.025
397	R	365	74.2	0.021
112	R	340	70.5	0.024
112	R	340	70.5	0.021
112	R	350	72.0	0.016
112	R	350	72.0	0.017
112	R	350	72.0	0.017
112	R	350	72.0	0.018
114	R	395	78.6	0.021
114	R	395	78.6	0.020
113	R	435	84.4	0.024
113	R	435	84.4	0.020
113	R	440	85.1	0.024
113	R	440	85.1	0.023
111	R	430	83.6	0.021
111	R	430	83.6	0.018
398	R	350	72.0	0.026
398	R	350	72.0	0.023
397	R	380	76.4	0.027
397	R	380	76.4	0.021
113	R	410	80.8	0.013
113	R	410	80.8	0.015
112	R	355	72.7	0.015
397	R	395	78.6	0.016
397	R	395	78.6	0.014
113	R	440	85.1	0.015
111	R	435	84.4	0.017
111	R	435	84.4	0.017
112	R	350	72.0	0.017
112	R	350	72.0	0.021

Continued

Animal	Activity	Body weight (kg)	$W^{0.73}$	Average O_2 consumption ($l/min/kg^{0.73}$)
114	R	405	80.1	0.014
114	R	405	80.1	0.019
397	R	375	75.7	0.019
397	R	375	75.7	0.019
398	R	330	68.9	0.016
398	R	330	68.9	0.016
112	R	345	71.2	0.021
112	R	345	71.2	0.018
114	R	400	79.3	0.016
114	R	400	79.3	0.020
112	R	350	72.0	0.016
114	R	350	72.0	0.024
113	R	440	85.1	0.021
113	R	440	85.1	0.019
113	R	440	85.1	0.014
111	R	430	83.6	0.017
397	R	375	75.7	0.014

APPENDIX 10

Energy expenditure and walking speed of Bunaji draught bulls walking on ploughed and unploughed upland in the sub-humid zone of Nigeria.

Animal	Activity	E_w (J/m/kg)	Walking speed (m/s)
398	WU	1.77	0.94
398	WU	1.93	0.85
398	WU	1.63	1.00
398	WU	1.49	1.14
398	WU	1.45	1.19
398	WU	1.46	0.84
398	WU	1.43	0.93
111	WU	1.40	0.62
111	WU	1.56	0.71
111	WU	1.90	0.71
111	WU	1.42	0.94
111	WU	1.29	0.94
111	WU	1.29	1.10
111	WU	1.32	1.04
114	WU	1.31	0.72
114	WU	1.86	0.85
114	WU	1.46	1.05
114	WU	1.50	1.09
114	WU	1.44	1.05
114	WU	1.88	0.81
114	WU	1.44	0.85
112	WU	1.53	0.73
112	WU	1.46	0.84
112	WU	1.35	1.03
112	WU	1.33	1.10
112	WU	1.24	1.10
770	WU	1.61	1.10
770	WU	1.46	1.10
770	WU	1.37	1.03
663	WU	1.38	1.20
663	WU	1.18	1.27
663	WU	1.16	1.23
113	WU	1.35	1.04
113	WU	1.37	1.02
113	WU	1.41	1.00
397	WU	1.45	0.93
397	WU	1.51	0.93
397	WU	1.58	0.95

Continued

Animal	Activity	E_w (J/m/kg)	Walking speed (m/s)
113	WPU	3.11	0.62
113	WPU	3.25	0.59
113	WPU	2.77	0.77
113	WPU	3.93	0.70
112	WPU	2.40	0.57
112	WPU	2.11	1.17
112	WPU	2.55	0.86
397	WPU	3.30	0.73
397	WPU	2.92	0.76
397	WPU	2.78	0.87
397	WPU	2.84	0.85
397	WPU	2.37	0.78
663	WPU	2.80	1.00
663	WPU	3.10	0.97
663	WPU	2.72	1.08
111	WPU	2.88	0.91
111	WPU	2.94	0.91

Example calculation : animal 397, WU

Resting average O_2 cons. (l/min)	1.55
Walking average O_2 cons. (l/min)	2.72
O_2 used for walking (l/min)	1.18
Speed (m/s)	0.93
Body weight (kg)	300
E_w (J/m/kg)	1.45

Resting average O_2 cons. (l/min)	1.55
Walking average O_2 cons. (l/min)	2.77
O_2 used for walking (l/min)	1.22
Speed (m/s)	0.93
Body weight (kg)	300
E_w (J/m/kg)	1.51

Resting average O_2 cons. (l/min)	1.55
Walking average O_2 cons. (l/min)	2.83
O_2 used for walking (l/min)	1.28
Speed (m/s)	0.95
Body weight (kg)	300
E_w (J/m/kg)	1.58

APPENDIX 11

Energy expenditure and walking speed of Bunaji draught bulls walking on ploughed and unploughed dry fadama in the sub-humid zone of Nigeria.

Animal	Activity	E_w (J/m/kg)	Walking speed (m/s)
113	WDF	1.85	1.00
113	WDF	1.64	0.97
111	WDF	1.97	0.92
114	WDF	1.11	0.93
398	WDF	2.00	0.73
398	WDF	1.69	0.69
397	WDF	1.67	1.04
397	WDF	1.53	0.85
397	WDF	1.63	0.92
112	WDF	2.10	0.68
112	WDF	1.92	0.88
112	WDF	1.77	0.87
112	WDF	1.97	0.88
113	WPDF	2.35	1.00
113	WPDF	3.00	0.80
111	WPDF	2.87	0.76
397	WPDF	5.17	0.80
397	WPDF	5.17	0.73
112	WPDF	2.95	0.78
112	WPDF	2.61	0.70
114	WPDF	3.00	0.64
114	WPDF	3.50	0.63
113	WPDF	4.92	0.69
113	WPDF	4.83	0.66
113	WPDF	6.19	0.63
113	WPDF	2.71	0.88
111	WPDF	4.72	0.76
111	WPDF	2.41	0.75

Continued

Analysis of variance

Varaite 1: Energy cost of walking.

Source of variation	**DF**	**SS**	**MS**	**VR**	**P**
Fact 1 (Soil)	5	665.82	133.16	127.52	0.000
Residual	114	119.05	1.04		
TOTAL	119	784.87			

Fact 1	WU	WPU	WDF	WPDF	WWF	WPWF
	1.48	2.87	1.76	3.76	3.29	8.58
Rep	38	17	13	15	19	18

Variate 2: Walking speed.

Source of variation	**DF**	**SS**	**MS**	**VR**	**P**
Fact 1	5	1.488	0.298	16.82	0.001
Residual	114	2.016	0.0177		
TOTAL	119	3.504			

Fact 1	WU	WPU	WDF	WPDF	WWF	WPWF
	0.97	0.83	0.87	0.75	0.80	0.65
Rep	38	17	13	15	19	18

APPENDIX 12

Energy expenditure and walking speed of Bunaji draught bulls walking on ploughed and unploughed wet fadama in the sub-humid zone of Nigeria.

Animal	Activity	E_w (J/m/kg)	Walking speed (m/s)
112	WWF	3.34	0.85
112	WWF	2.72	0.90
112	WWF	3.06	0.96
114	WWF	3.44	0.75
114	WWF	3.63	0.70
114	WWF	4.25	0.73
114	WWF	4.20	0.87
397	WWF	2.34	0.72
398	WWF	3.49	0.70
398	WWF	3.14	0.85
111	WWF	2.81	0.77
111	WWF	3.24	0.75
113	WWF	2.70	0.94
113	WWF	2.80	0.78
112	WWF	2.90	0.81
112	WWF	4.10	0.76
112	WWF	4.20	0.87
113	WWF	3.31	0.77
112	WWF	2.90	0.78
111	WPWF	13.2	0.45
111	WPWF	8.70	0.54
111	WPWF	6.90	0.70
111	WPWF	4.60	0.89
112	WPWF	5.30	0.82
112	WPWF	10.40	0.56
112	WPWF	11.30	0.49
113	WPWF	9.75	0.64
113	WPWF	8.30	0.56
113	WPWF	7.90	0.67
398	WPWF	12.10	0.53
398	WPWF	9.90	0.66
398	WPWF	7.30	0.77
114	WPWF	7.10	0.70
114	WPWF	8.50	0.63
114	WPWF	9.00	0.56
397	WPWF	7.40	0.80
113	WPWF	6.80	0.74

APPENDIX 13

Efficiency of doing work, walking speed and DADF of Bunaji bulls ploughing and harrowing upland in the sub-humid zone of Nigeria.

Animal	Activity	Efficiency of doing work	Walking speed (m/s)	DADF (N)
111	HU	0.30	0.63	739
111	HU	0.29	0.63	737
111	HU	0.23	0.62	634
113	HU	0.26	0.61	784
113	HU	0.24	0.53	827
113	HU	0.23	0.50	710
114	HU	0.41	0.54	835
114	HU	0.38	0.66	655
114	HU	0.39	0.63	588
112	HU	0.37	0.75	654
112	HU	0.43	0.99	628
112	HU	0.44	0.83	599
398	HU	0.42	0.67	1047
398	HU	0.29	0.68	906
398	HU	0.30	0.59	843
397	HU	0.36	0.71	896
397	HU	0.29	0.76	834
397	HU	0.27	0.62	1102
114	PU	0.27	0.42	921
114	PU	0.39	0.47	659
114	PU	0.26	0.45	607
113	PU	0.31	0.49	535
111	PU	0.28	0.52	480
111	PU	0.30	0.58	518
111	PU	0.36	0.65	523
112	PU	0.35	0.67	631
112	PU	0.32	0.58	573
398	PU	0.37	0.79	848
398	PU	0.32	0.64	883
398	PU	0.32	0.63	800
397	PU	0.26	0.56	828
397	PU	0.24	0.60	763
397	PU	0.27	0.51	626
112	PU	0.20	0.39	638
112	PU	0.37	0.51	501
112	PU	0.36	0.51	512

Continued

Analysis of variance

Variate 1: Efficiency of doing work.

Source of variation	DF	SS	MS	VR	P
Fact 1 (cultivation)	1	0.006379	0.006379	1.79	—
Fact 2 (soil)	2	0.001902	0.000951	0.27	—
Fact 1 Fact 2	2	0.001313	0.000656	0.18	—
Residual	102	0.362617	0.003555		
Total	107	0.372210			

Variate 2: Walking speed.

Source of variation	DF	SS	MS	VR	P
Fact 1	1	0.032379	0.032379	3.77	—
Fact 2	2	0.375006	0.187503	21.81	0.01
Fact 1 Fact 2	2	0.077702	0.038851	452	—
Residual	102	0.877006	0.008598		
Total	107	1.362092			

Variate 3: DADF.

Source of variation	DF	SS	MS	VR	P
Fact 1	1	54329.3	54329.3	14.17	0.1
Fact 2	2	7903997	3941998	103.07	0.001
Fact 1 Fact 2	2	24877	12438	0.32	—
Residual	102	3911129	38344		
Total	107	1.E+0.7			

APPENDIX 14

Efficiency of doing work, walking speed and DADF of Bunaji bulls ploughing and harrowing dry fadama in the sub-humid zone of Nigeria.

Animal	Activity	Efficiency of doing work	Walking speed (m/s)	DADF (N)
112	HDF	0.35	0.50	1293
112	HDF	0.36	0.51	1285
112	HDF	0.40	0.52	1301
114	HDF	0.35	0.46	1253
114	HDF	0.36	0.49	1281
114	HDF	0.35	0.57	1269
113	HDF	0.30	0.42	1180
113	HDF	0.23	0.45	1148
113	HDF	0.33	0.52	1291
111	HDF	0.25	0.38	1248
111	HDF	0.29	0.41	1251
111	HDF	0.30	0.46	1254
398	HDF	0.38	0.63	1243
398	HDF	0.36	0.67	1221
398	HDF	0.37	0.68	1201
397	HDF	0.31	0.58	1267
397	HDF	0.25	0.55	1263
397	HDF	0.28	0.45	1245
397	PDF	0.23	0.42	1676
111	PDF	0.23	0.48	960
111	PDF	0.17	0.39	980
111	PDF	0.15	0.36	997
113	PDF	0.39	0.65	1031
113	PDF	0.32	0.61	824
114	PDF	0.36	0.59	1254
114	PDF	0.33	0.51	1150
114	PDF	0.27	0.46	1146
397	PDF	0.40	0.56	1249
397	PDF	0.30	0.56	1225
397	PDF	0.32	0.47	1150
398	PDF	0.29	0.48	1066
398	PDF	0.33	0.50	1248
398	PDF	0.31	0.50	1229
112	PDF	0.36	0.72	1000
112	PDF	0.39	0.71	1010
112	PDF	0.29	0.47	1137

APPENDIX 15

Efficiency of doing work, walking speed and DADF of Bunaji bulls ploughing and harrowing wet fadama in the sub-humid zone of Nigeria.

Animal	Activity	Efficiency of doing work	Walking speed (m/s)	DADF (N)
113	HWF	0.27	0.43	1346
113	HWF	0.25	0.56	1102
113	HWF	0.27	0.38	1676
398	HWF	0.35	0.42	1301
398	HWF	0.36	0.39	1290
398	HWF	0.36	0.57	1349
112	HWF	0.31	0.43	1745
112	HWF	0.33	0.36	1993
112	HWF	0.35	0.45	1657
114	HWF	0.35	0.39	2109
114	HWF	0.27	0.48	1237
114	HWF	0.29	0.52	1078
112	HWF	0.30	0.55	1606
112	HWF	0.27	0.63	1239
112	HWF	0.24	0.52	1536
111	HWF	0.40	0.34	1432
397	HWF	0.37	0.54	1247
397	HWF	0.25	0.47	1156
113	PWF	0.40	0.59	1305
113	PWF	0.29	0.44	1347
113	PWF	0.30	0.42	2203
111	PWF	0.26	0.44	1231
111	PWF	0.28	0.38	1345
111	PWF	0.40	0.36	1303
112	PWF	0.35	0.43	1281
112	PWF	0.22	0.47	1102
112	PWF	0.23	0.44	1245
114	PWF	0.37	0.46	1087
114	PWF	0.25	0.51	1102
397	PWF	0.26	0.49	1305
397	PWF	0.26	0.56	1161
112	PWF	0.34	0.46	1077
112	PWF	0.37	0.42	1031
112	PWF	0.37	0.44	1237
398	PWF	0.27	0.48	1250
398	PWF	0.27	0.56	1161

APPENDIX 16

DLW research proposal currently submitted to ILCA for possible funding.

1. Thrust: **ANIMAL TRACTION**

2. Theme: **Feeding strategies for draught animals**

3. Short title: **Medium term energy use by cattle — DLW method.**

4. Full title: **The determination of energy use during critical times of the year by draught oxen, cows and calves in sub-humid zones using the DLW method.**

5. Locations: **Kaduna; Debre Zeit; Edinburgh, Scotland; Hohenheim, Germany.**

6. Executing persons:
   - (a) ILCA staff: **P. Lawrence**, **J. Dijkman**
   - (b) Others: **R.A. Pearson, Edinburgh; K. Becker, Hohenheim**

7. Duration: 3 years
   Progress reports: 6 monthly

8. Research summary:

a. Justification and background:
Much of the work on the nutrition of cattle in which ILCA has been involved in the sub-humid zones has focussed on the availability of and requirements for proteins and minerals. Some of these results have appeared anomalous probably because insufficient attention was given to the energy status of the animals being tested. Over 90% of the nutrients eaten by ruminants at maintenance level are used simply to provide biologically useful energy and even in 'production' animals such as beef and dairy cattle the proportion is usually 50%. Lack of energy producing nutrients in an animal's diet is more rapidly and acutely felt than the lack of any other nutrient except water.

In the sub-humid zones, the energy balance of cattle is often particularly precarious. This is especially true of animals that suddenly find themselves faced with demands on their energy reserves which are large and unavoidable. Two such cases are cows with young calves and draught cattle at the beginning of the ploughing season. Feeding and management strategies designed to avoid damaging stress in these situations rely heavily on a knowledge of the energy economy of such animals during crucial periods of one to a few weeks.

Traditionally the study of energy balances in large ruminants has involved the measurement of gaseous exchange usually by means of a respiration chamber (Blaxter, 1962). Such techniques are obviously unsuitable for studying free ranging or working animals. While several methods and potential methods can be applied to such animals when they are actually working, recent work has shown that the underlying 'basal' energy expenditure is also affected by work (Lawrence *et al*, 1989; Lawrence *et al*, 1989) and so to obtain an accurate and complete picture of the energetic economy of working animals, some method is required which will measure the total energy used over a period of several days and not just the energy expenditure whilst working.

It appears that the DLW method would be appropriate in this context. The method relies on the fact that hydrogen is lost from the body mainly in water, whereas O_2 is lost in both water and as part of the CO_2 molecule. The O_2 atoms in body water and those in CO_2 are kept in equilibrium due mainly to the action of the enzyme carbonic anhydrase. Therefore if an animal drinks a dose of water in which both the hydrogen and O_2 are labelled, the specific activity of the O_2 in the body water will decrease at a faster rate. The difference in the two rates of decrease times the volume of the total body water (which may be estimated from the initial equilibrium specific activity) will give the loss of CO_2 from the body. If certain assumptions are made regarding the RQ, then reasonably accurate estimates can be made of the total energy consumption of the animal. In the field the method simply involves dosing the subject with water made from the non-radioactive isotopes of ^2H and ^{18}O and then taking samples of urine blood or saliva at intervals during the next 7 — 14 days for analysis by mass spectroscopy.

The theoretical basis of this method was originally worked out by Lifson *et al* (1955), and has been applied to a variety of animals from mice (Lifson and Mclintock, 1966) to men (Schoeller and Van Santen, 1982).

Over the last few years the DLW method has been further refined and adapted for use with sheep (Midwood *et al*, 1989). The theory of the method has been elaborated to allow for CH_4 production by ruminants (Midwood, Haggarty, McGaw and Robinson, 1989), sequestration of water into body components such as fats and variation in total body water. A further possible source of error occurs because of the differential fractionation of isotopes during physical equilibration of water. Quantitatively the most important of these equilibria is that occurring during evaporation of water from the respiratory tract. Haggarty *et al* (1988) have shown how these errors can be allowed by introducing a third isotope into the water. The only two possibilities are ^{17}O and ^3H. The former is prohibitively expensive and the latter is slightly radioactive, and it would be difficult to avoid contamination of the environment if it were given to working animals. In any case the potential errors produced by evaporative fractionation at the lung's surface are not large and could be ignored in this study without invalidating the results. It would obviously be of great value if this technique could also be applied to other ruminant species especially cows and draught animals, but to do this it must first be proved against more conventional methods.

b. *Objectives*

— to validate the DLW method against continuous (24 h/day, seven days a week) measurements of gaseous exchange using cows and draught oxen at the CTVM, University of Edinburgh, Scotland.

— alternatively, the necessary equipment for the validation study could be set up at Debre Zeit at an estimated cost of US $ 120,000.

— to develop the necessary analytical techniques at the *Institut fur Agrartechnik, Universitat Hohenheim*, Germany, for the determination of O and H, or the Rowett Research Institute, Scotland.

— to apply the DLW method to draught bulls in Kaduna, Nigeria, during the intensive work period at the beginning of the ploughing season.

— to measure the total energy balance of cows and calves in Kaduna and to apply the 'dose to mother' technique (Coward and Prentice, 1984) in order to measure milk consumption by calves.

— to investigate the applicability of the DLW method to draught cows.

c. Work programme

i. Validation of the DLW method for use with draught oxen and cows. (Scotland/Ethiopia)

Experimental method

Four small (300 kg) oxen and four cows in the third month of pregnancy will be procured at the CTVM, Scotland / Debre Zeit, Ethiopia. All animals will be kept in climatic chambers programmed to simulate temperature and humidity regimes similar to those of Kaduna in April/May. Animals will be handled regularly and spend several days in the respiration chambers during a five to six month acclimatisation period so they can be become thoroughly familiar with the noise of the fans etc. In addition, the oxen will work one day per week for 5 h pulling a load in N numerically equal to their body weight round a circular race or track. All animals will be fed a fixed amount of a mixed forage and concentrate diet calculated to provide enough metabolisable energy for maintenance, work and (for the cows) pregnancy, but not enough for any substantial weight gains. The food will be offered in two equal meals at 09.00 and 17.00 h and all animals will have free access to water (intake automatically monitored) and a salt lick.

The procedure for testing the DLW method will be different for the cows and oxen.

a) Oxen

Each ox in turn will spend three days in the open circuit respiration chamber, during which time O_2 consumption and the production of CO_2 and CH_4 will be measured continuously. At 09.00 h on the fourth day the ox will be given a dose of water containing 45 g of $^2H^{18}O$, immediately after its morning meal. Continuous measurement of the gaseous exchange will continue for a further 14 days. On days two to six inclusive the ox will work as described above (still measuring its gaseous exchange). Samples of urine will be taken at four hourly intervals initially, falling to daily sampling after day 10. Samples will be preserved for later analysis by mass spectroscopy. During the whole 14 day period, total food intake and total production of faeces and urine will be measured and samples taken for determinations of DM, GE, carbon and Kjeldahl nitrogen. Duplicate determination will be done with each ox.

b) Cows and calves

After the birth of its calf, the cow will be trained, as soon as is feasible, to become accustomed to a daily routine of suckling its calf for two half h periods each day. As soon as this routine has become established, the cow will spend 14 days in the respiration chamber, during which she will be dosed with DLW, gaseous exchange will be measured and samples will be taken as described for the oxen above. Unlike the oxen, the cow will not work, but she will continue to suckle her calf twice daily and milk samples will be taken. The gaseous exchange of the calves will not be measured, but they will be weighed before and after suckling to determine milk intake and samples of urine will be taken to determine the extent of the transfer of label from cow to calf.

Processing results
The ability of the DLW method to predict CO_2 production by oxen and suckling cows can be assessed by comparing it with the direct measurement of CO_2 output. The data collected will also enable the calculation of energy expenditure in three main ways:

a) From gaseous exchange (Brouwer, 1965)
b) From carbon/nitrogen balance (Blaxter and Rook, 1964)
c) From DLW (Midwood *et al*, 1989)

Thus the ability of the DLW method to predict total energy expenditure can also be made. In the case of the calves, the intake of milk can be checked against the intake predicted from the DLW method and estimates can be made of the total energy expenditure of the calves (Coward and Prentice, 1984). No independent check can be made on this last quantity unless separate measurements are taken of the gaseous exchange of the calves.

The decay curves for the specific activities of the two isotopes can be compared with the actual energy expenditure in cases where the rates of water excretion and energy expenditure vary greatly (working oxen) to see whether these circumstances introduce any systematic bias and suitable correction procedures will be established.

ii. Investigation of the energy economy of hard working animals in poor body condition (Nigeria/Ethiopia)
Four farmers' oxen should be used for this trial. They should be as 'typical' as possible as regards body condition and level of feeding. To aid analysis of the results, feeding should be standardised as to quality and daily intake whilst keeping as near as possible to local practises. The oxen will be trained to work wearing face masks so that their O_2 consumption during work can be measured using the Oxylog (Dijkman, 1989). The trial consists simply in giving each animal a dose of DLW as in part i) at the start of the ploughing season and taking urine samples during the next 14 days, while at the same time taking direct measurements of O_2 consumption during work, total work done, total distance travelled and elapsed working time. The results should answer the following questions: a) What is the total energy expenditure during this critical time both in absolute terms and in relation to energy reserves? and b) What proportion of the energy is used for work, how much for maintenance (difference of the Oxylog and DLW results) and does work appear to affect maintenance requirements?

iii. Investigation of the energy economy of cows and calves.
As for the oxen, cows should be as 'typical' as possible and it is worthwhile to standardise their diet. Oxylog measurements can be taken at selected periods before and after parturition (if possible from the calf as well), but the main objective of the trial is to find out the total energy cost to the cow of early lac-

tation and to draw general conclusions as to the energy intake and expenditure of the calf.

d. Expected output

1. To use the data obtained to devise improved feeding and management strategies to increase productivity and alleviate stress.

2. To establish the DLW method as a viable research tool for use with large ruminants in the field and to make the technique available to the National Agricultural Research Services (NARS).

e. Collaboration

1. *Institut fur Agrartechnik, Universitat Hohenheim,* Germany.
2. CTVM, University of Edinburgh, Scotland.
3. Rowett Research Institute, Scotland.

9. Publications

1. Recommendations for feeding and management strategies.
2. Various research papers.

Approximate time scale.

0 — 14 months:	Literature review and verification studies on cows and working oxen at the CTVM/Debre Zeit and setting up and operation of analytical techniques at Hohenheim. Possible orientation visit to Kaduna (2 — 3 weeks) during this time.
15 — 28 months:	Application of the DLW method to cows, calves and oxen in Nigeria accompanied by O_2 consumption measurements using the modified Oxylog for comparison.
29 — 36 months:	Draw up recommendations for feeding and management strategies.

Prepared by: Peter Lawrence, ILCA
Johannes Dijkman

APPENDIX 17

Project proposal for integrated draught animal farming system research.

ILCA/West African Rice Development Authority (WARDA)

SUB-PROJECT PROTOCOL PROPOSAL (New sub-project)

1.	Thrust:	Animal Traction	
2.	Themes:	Animal Traction-Based Tillage Systems for Lowland Rice Feeding Strategies for Draught Animals	
3.	Short Title:	Animal Tillage for Lowland Rice	
4.	Full Title:	The Development of Animal Traction-Based Tillage Systems for Irrigated and Rain-fed Lowland Rice Production in West Africa	
5.	Location:	WARDA, Mbé Research Station, Ivory Coast	
6.	Executing Persons:	Cropping System Agronomist Animal Scientist Agricultural Anthropologist/Economist Agricultural Engineer	WARDA ILCA
7.	Duration:	3 years Progress reports: 6 monthly	

8. Research Summary:

JUSTIFICATION AND BACKGROUND

Weeds represent the major constraint in rain-fed lowland rice (International Institute for Tropical Agriculture [IITA], 1986; WARDA, 1988). Farmers employ a combination of primary and secondary weed control methods. In addition to primary control by hand, mechanical interrow cultivation and herbicide, these include land preparation, water control and planting method (O'Brien and Price, 1983). The specific combination of methods employed by a farmer will depend on the soil texture, soil moisture, the level of weed infestation and the availability of power, cash and labour. It is widely acknowledged that there is a tremendous diversity in the soil and water conditions of the small valleys of West Africa. With the variability in the resource endowment of West African farmers, this has resulted in the evolution of many different lowland rice-based cropping systems that are faced with different constraints. It is important that these different cropping systems be adequately characterized so that only those technologies appropriate to particular systems can be tested.

Tillage

The importance of land preparation in weed control in lowland rice is often overlooked. Farmers in Asia typically combine one or more inversion ploughings in primary tillage with one or more harrowings or puddlings (Barker and Hayami, 1984). Puddling greatly reduces subsequent weed growth. [The other benefit of puddling, which is the reduction of percolation losses, is unimportant in the small valleys of West Africa because the surface water table prevents water infiltration.]

Because animal traction technology has been introduced into West Africa from Europe there has been little development of animal traction-based technologies for rice production. In contrast, animal traction has been introduced into Madagascar from Asia with the result that there is a wide range of fixed and rotary lowland equipment currently used by farmers. It is important to identify and evaluate these animal traction lowland rice tillage implements under the range of soil and water conditions that occur in West Africa. Of particular importance is the identification of lowland ploughs that have a low draught force requirement yet completely invert the plough layer.

Different tillage combinations will be developed and indexed according to specific soil conditions, degree of water control, level of weed infestation and resource requirement (cash, power and labour). This information will be used to develop a tillage rating system that includes both workability ("ease of tillage") and trafficability ("ease of displacement") of different lowland soil and water combinations. A similar system, based primarily on the mechanical impedance and bearing capacity of a soil at different levels of soil moisture, has been developed for use with two wheel tractors in Asia (Kisu, 1985). The development of this rating system is particularly important in lowland soils due to the interaction of soil texture and soil water. When dry, tillage of the fine textured soils of the small valley bottoms is problematic due to the excessive draught force requirement. This requirement is greatly reduced when the soils are wetted. However soil saturation also reduces the bearing capacity of the soil which increases the difficulty and energy requirement associated with walking. This interplay of workability and trafficability highlights the importance of evaluating animal as well as equipment performance under the full range of soil and water conditions.

Planting Method

Planting methods include dry seeding, wet seeding and transplanting. Dry seeding is advantageous in areas where the growing season is short or where farmers wish to double crop. Wet seeded rice requires substantially less time than transplanting but necessitates repeated hand weeding or the use of herbicides (Lubigan, Estorninos and Moody, 1982). Thorough land levelling and good water control are important in wet seeded rice in order to prevent submergence of rice seedlings. Transplanting enables the farmer to delay planting until the more rainfall dependent upland activities have been completed. Adequate land preparation and transplanting quite often removes the need for primary weed control. However delayed transplanting is only feasible in valleys with water control or where the water table persists, prolonging the growing season past the cessation of the rains.

The choice of planting method depends on the availability of labour and power. In The Gambia two opportunity windows were identified for the use of oxen in land preparation. On the North Bank, where women traditionally dry seed lowland rice, there is the possibility of dry tillage prior to the onset of the rains and upland cropping activities. On the South Bank, where women traditionally transplant lowland rice, there is the possibility of wet tillage in the middle of the rainy season after upland land preparation has been completed.

Water Control

Many authors consider shallow flooded conditions the cornerstone of a lowland rice weed control system. Water control is required for satisfactory soil puddling. Post transplanting flooding suppresses weed growth while resulting in an optimum environment for the rice plant. Unfortunately few small valleys in West Africa have been developed for water control. Rather soil moisture is maintained during the rainy season by a surface water table.

There is a need to develop weed control systems for lowland rice without water control. A key constraint in land preparation is harrowing as the lack of standing water prevents puddling. Rotary puddling implements are not feasible as they tend to pack with mud in the absence of standing water. There is a need to identify and develop fixed tine harrows for secondary tillage under these conditions.

Weed Control

There are three primary weed control methods: hand and hand hoeing, mechanical cultivation and herbicide. Appropriate primary weed control technologies need to be identified for both dry- and wet-seeded rice. When rice is broadcast seeded, hand weeding is tedious and delays invariably result in significant yield loss. In Kufana in 1991 hand weeding required 60 to 80 mandays/ha regardless of whether the land was manually tilled or tilled with oxen. Without hand weeding, yield losses reached 50% in Kufana, Nigeria (Lawrence, personal communication). Seeding dry- and wet-seeded rice in rows allows earlier weeding and reduces primary weed control time. With shallow flooding, rotary weeders can be used in interrow cultivation. Herbicides provide early season weed control in direct seeded rice which reduces the yield loss due to weeds and subsequent hand weeding time. However, the use of herbicides depends on the availability of cash to the farmer which may depend on the production of lowland rice as a cash rather than a subsistence crop.

Draught Animal Power Source

The introduction of any kind of novel power source into a farming system raises many questions ranging from social acceptability to technological efficiency. This is particularly true of draught animals where account must be taken not only of the working capacity of the animal but also of its food supply, its susceptibility to disease and its use for purposes other than draught e.g. meat production, milk production and reproduction.

In the lowland areas of the Ivory Coast rice cultivation is generally done by hand. Attempts to introduce small scale mechanization (rotavators and mini tractors) have generally failed once the machines have started to wear out.

An obvious intermediate technology would be to use draught animals. In most parts of the country the local breed of cattle is Baoulé (*Bos taurus*). These animals usually reach an adult weight of 200 — 250 kg and are generally perceived as being too small to till the heavy, wet soils of the bas fonds. There is however no documentary evidence to support this and well-fed Baoulé oxen regularly work at the WARDA station at Mbé on lowland soils. An alternative breed of cattle would be the local Zebu or Fulani either pure or crossed with Baoulé which attain weights of around 300 kg. A third alternative would be to use Asiatic water buffalo (*Bubalus bubalis*). These are heavier than either of the local breeds of cattle and are used extensively in other parts of the world for rice cultivation under similar edaphic and hydrologic conditions to those found in the bas fonds of West Africa. There is a breeding herd of these animals in St. Louis, Senegal from which specimens may be obtained for the present study. Although the present study is concerned primarily with the work output and feeding of these animals, it should be noted that the Asiatic buffalo has a reputation for being susceptible to trypanosomiasis and has never been introduced into the Ivory Coast. Careful notes must therefore be kept of the health status of these animals as well as their acceptability to the local people as producers of meat and milk .

OBJECTIVES

(1) to survey the technologies and husbandry involved in the use of animal traction by farmers in the Savanna zone of West Africa.

(2) to develop weed control combinations for the range of edaphic, hydrologic and socio-economic conditions in which rice is grown in the small valleys of West Africa. In particular, control combinations will include tillage, planting method, water control and type of primary weed control.

(3) to identify appropriate animal traction lowland ploughs and harrows for use in secondary tillage and puddling. In particular Asian ploughs will be tested against the European design upland plough currently used in West Africa and rotary puddlers will be identified for use under flooded conditions and fixed blade harrows for use under saturated but unflooded conditions.

(4) to classify and index these technologies according to the soil texture, hydrology, level of weed infestation and level of power, labour and cash necessary for their efficient use. This indexing will allow the weed control technologies to be targeted to the appropriate lowland cropping systems for farmer evaluation.

(5) to train, test and compare four types of draught animals: Baoulé, Zebu, Zebu x *Bos taurus* and water buffalo for speed, stamina, food intake, liveweight change and performance in the field in relation to soil and water characteristics.

(6) to monitor the resistance of these animals to disease and their acceptability to local farmers.

(7) to develop a workability and trafficability rating system of animal traction-based lowland tiliage.

(8) to compare three different power sources in the cultivation of lowland rice: hand, animal, tractor

(9) to test the different technologies and husbandry methods on farm

WORK PROGRAMME

(1) The Identification of Constraints to the Farmer Adoption of Animal Traction-Based Lowland Tillage Technologies

Lal (1991) poses the rhetorical question as to why animal traction has not been adopted by more farmers in West Africa. He suggests that the answer lies in the evaluation of appropriate tillage systems within particular farming systems. There appear to be several interrelated reasons why animal traction use is not more widespread for the wet tillage of riceland in the small valleys of West Africa. These include the following:

(1) The potential adopter does not perceive that the technology is relevant as he has access to power tillers or to tractors for lowland tillage (Pingali, Bigot and Binswanger, 1987).

(2) The potential adopter does not have access to the technology (Luning, 1984). This is clearly the case in the humid forest zone where cattle and draught animal technologies are unavailable, but it is also the case in many parts of the savanna region where lowland rice is cultivated by women while men control access to animal traction technology (Posner, Crawford and Kamuanga, 1991).

(3) The potential adopter may perceive that there are conflicts between the use of his work oxen for both wet tillage in the lowlands as well as upland tillage (Posner *et al*, 1991).

(4) The potential adopter may lack the knowledge to successfully use animal traction-based tillage combinations due to the paucity of extension programs on the use of animal traction for wet tillage. Rather extension efforts have been closely tied to official government policy which, until recently, has been promoting tractor- and power tiller-based technologies in an attempt to by-pass the animal traction mechanization stage (Pingali *et al*, 1987).

(5) Animal traction-based wet tillage technologies are different from and more involved that the upland tillage systems which the farmer knows. This makes adoption and sustained use more difficult.

(6) The farmer may perceive that there are risks associated with using his work oxen under saturated soil conditions.

These hypotheses need to be tested first through informal surveys using a focused set of guide-lines (Annex A) and later through formal surveys.

(2) The Development and Classification of Sustainable Weed Control Technologies for Rain-fed Lowland Rice.

The following 4 x 3 factorial will be conducted under both shallow flooded conditions (irrigated) and under unflooded but saturated soil conditions (hydromorphic)

Factor 1: *Tillage*

Hand hoe ploughing twice
Draught animal single mouldboard ploughing 1 x followed by harrowing 1 x
Draught animal single mouldboard ploughing 1 x followed by harrowing 2 x
Draught animal single mouldboard ploughing 2 x followed by harrowing 2 x

Factor 2: *Planting method*

Transplanting
Broadcast seeding
Row seeding

Data to be gathered

* weed suppression due to the different tillage operations (% cover using the meter rule technique)
* weed biomass at 35 days after seeding or days after transplanting
* date of and time necessary to complete all tillage, planting and weeding operations
* rice yield and yield parameters.
* work output of animals for primary and secondary tillage operations
* O_2 and energy consumption of animals during primary and secondary tillage operations

(3) The appropriateness of different types of draught animals for rice cultivation in small valleys in West Africa

(i) *Standard work tests and physiological response to work*

Eight Baoulé cattle, 8 Zebu cattle, 8 Zebu x *Bos taurus* cattle and 8 water buffalo will be trained to perform the two tests detailed below (Annex B). The first is a test of speed and the second of stamina. During each test, heart rate, respiration rate and rectal temperature will be taken before and immediately after the test and in the case of the endurance test at intervals during and for 1 hour after. O_2 consumption will be measured using a modified Oxylog (Annex C). Tests should be continued over a period of several weeks until at least 6 readings for both tests for all animals have been obtained.

(ii) *Performance in the field in relation to soil and water characteristics*

The different types of soil in the local lowland areas will be characterized and classified. Each major soil type will be cultivated for rice production (i.e. ploughing and harrowing) using the three types of draught animals working in pairs. For each combination of draught animal, soil type and operation the following will be measured over a 3 h period:

Elapsed working time
Distance travelled
Work done
O_2 consumption

From which can be derived, average draught force, speed of working, power output, energy expenditure and energetic efficiency of working. Standard statistical methods will be used to assess the relative performance of the three types of draught animals.

In addition the site will be characterized according to:

Soil texture
Soil moisture
Penetrometer resistance

(iii) *Food intake and live weight change*

The feeding trials will run concurrently with (ii) above. "Representative" diets consisting of locally available forages and crop residues will be identified. All animals will be kept in stalls when not working and will wear woven face masks when in the field. Food will be offered *ad libitum* and total DMI for all animals determined using standard procedures. All animals will be weighed three times a week first thing in the morning. Animals will work all week on alternate weeks so that their food intake and weight gains can be compared between animals, between types of animal and according to whether they were working or idle.

(iv) *Disease resistance and acceptability*

During the workability and trafficability experiments careful monitoring and recording of the health status of the three types of draught animals will be carried out. Routine health care will involve vaccinations and prophylactic treatment of endo and exo parasites. Blood and faecal samples will be taken monthly and checked for parasites.

Acceptability: during the experimental periods, ease of training and handling during work will be closely monitored. The initial survey (1) will provide answers to the acceptability to farmers of the different draught animals available in the Ivory Coast. A similar study will be carried out in Senegal in collaboration with the *Projet Buff*, to assess the acceptability of buffaloes to animal traction farmers in the Savanna zone of West Africa.

(4) The Comparison of Power Source in the Cultivation of Rain-fed Lowland Rice

Results from the experiments carried out under (2) will have indicated which combination of cultivation methods gave the best results for each soil conditions. The specific tillage and planting method under both shallow flooded conditions (irrigated) and under unflooded but saturated soil conditions (hydromorphic) will be compared under the different power sources available : manual, animal and tractor.

Data to be gathered

* date of and time necessary to complete all tillage, planting and weeding operations
* financial inputs necessary to complete all tillage, planting and weeding operations
* rice yield and yield parameters.
* work output of animals for primary and secondary tillage operations
* financial outputs connected to each power source

(5) Testing of Different Technologies and Husbandry Methods on Farm

During all stages of the work programme described in (1) to (4), simultaneous on-farm controls will be carried out. The data gathered during the on-farm testing are similar to the data which will be gathered during the on-station experiments.

Expected Outputs

* Development of cultural calendars associated with direct seed and transplant lowland cropping systems
* Information on labour requirements in different flood regime-tillage-planting systems
* Information on the effect of tillage frequency on subsequent weed suppression
* Assessment of the suitability of the three types of animal for work in the lowlands from a purely technological point of view and from factors such as the resistance of the animals to disease and their acceptability to local farmers
* Development of a workability and trafficability rating system of animal traction-based lowland tillage
* Assessment of the economical inputs and outputs connected to the use of different power sources in the cultivation of rain-fed lowland rice

Collaboration

1. *IDESSA — Elevage*
2. *CIDT — Agriculture/Elevage*
3. *Projet Buff, St. Louis Senegal*

9. PUBLICATIONS

1. See expected outputs
2. Various research papers

Time Inputs Personnel:

	year 1	2	3	4
Cropping Systems Agronomist :	100%	100%	100%	100%
Animal Scientist :	100%	100%	100%	100%
Economist :	25%	—	25%	25%
Agricultural Engineer :	5%	5%	—	—

Prepared by: *Peter Lawrence — ILCA*
Tom Remington — WARDA
Johannes Dijkman

Annex A

GUIDE-LINES FOR FARMER DISCUSSIONS (Rice Production Systems)

Land Preparation

(1) What tools does the farmer use in land preparation?
(2) How does the farmer prepare his land (scarification, mounds, ridges, inversion ploughing, combination of techniques)?
(3) When, in relationship to the onset of the rains, does he prepare his land? If land preparation is delayed, why?
(4) What is the influence of landscape position on tool selection, land preparation method and the time of land preparation?
(5) When is riceland prepared in relationship to other crops? Why this priority?
(6) What type of preparatory work is needed prior to soil tillage at different landscape positions in relationship to the timing of land preparation and the tools employed(slashing, burning, incorporation of residues)?
(7) Why does the farmer prepare the land the way he does?
(8) Have his land preparation methods changed recently and if so how and why?
(9) How is land preparation organized? Is an entire field completed prior to seeding or is a section prepared and seeded the same day? How is labour organized in land preparation? Family or hired labour?
(10) Is animal traction or tractor ploughing hired? What is the rate/ha?
(11) How does the farmer anticipate that his land preparation methods will change in the future?
(12) What type of animals are owned?
(13) What system does the farmer use in replacing his animals?
(14) Are cattle used in pairs or singly?
(15) Are donkeys used in land preparation?
(16) How long has the farmer used animal traction?
(17) How has his use of animal traction changed since he began using the technology?
(18) How does landscape position influence the use of animal traction?
(19) What are the problems associated with the use of draught animals in land preparation? How are these influenced by landscape position (soil texture and soil moisture)?
(20) What changes does the farmer anticipate in his land preparation methods in the future?
(21) What implements does the farmer own? What implements does he use most often? What implements does he not use and why?
(22) How did the farmer purchase his equipment and how does he repair them?
(23) In his opinion what can be done to increase the efficiency of animal traction use on his farm?

Planting

(1) How is the decision made to direct seed or transplant? Is standing water a prerequisite for transplanting? Is the planting decision influenced by expected weed control difficulties?
(2) For direct seeded rice, does the farmer broadcast seed, hill seed or row seed? Has he always seeded in this manner? If seeding method has changed recently, why?
(3) What tools are used in seeding (hand hoe, harrow, jab planter, rolling injection planter, planting line, other manual or animal traction seeders or tractor seeders)?
(4) How has tool use changed in the recent past?
(5) How does seeding method influence subsequent weed control?
(6) What ideas does the farmer have in making rice seeding more efficient?
(7) If the farmer row seeds, what row spacing does he use andwhy?
(8) If the farmer transplants, does he normally hire labour?
(9) Does he transplant randomly of in rows? Why?
(10) Does the farmer think that transplanting operations can be made more efficient?

Weeding

(1) Describe the weed control methods used in direct seeded and in transplanted rice.
(2) How has the farmer's weed control methods changed in the recent past? What is this change in response to?
(3) What are the most troublesome weeds for the farmer? Where do these occur on the continuum?
(4) What tools are used in weed control? Are these tools satisfactory?
(5) If the farmer owns draught animals, does he use them in row weeding rice? If not, does he use them to interrow cultivate maize or groundnuts? Why is the use of animal traction in weed control limited? Is the use of animal traction influenced by number of years experience in using draught animals?
(6) Does the farmer use herbicide? If so where (upland, lowland, both)?
(7) Is herbicide readily available? What are the names of the herbicides?
(8) How does the farmer feel that weed control can be improved?

Draught Animal Management

Animal Husbandry

(1) How and how often does the farmer feed his draught animals?
(2) Does the farmer feed his animals by-products? If so, what are these?
(3) Does the farmer use rice straw as a feed source?
(4) What type of draught animal does the farmer use? Why does he use this type of animal?
(5) What does the farmer think are the characteristics of a good draught animal?
(6) At what age are draught animals replaced? On what criteria is this decision made?

Animal Training

(7) At what age does the farmer begin training his animals?
(8) What is the source of his draught animals?
(9) What method of training is used? How long does training take?

Manure Management

(10) How is manure produced by draught animals managed?
(11) Is bedding/litter used?
(12) How is manure transported?
(13) List any other benefits associated with owning draught animals?

Animal Health

(14) What are the most common health problems encountered in draught animals?
(15) Does the farmer vaccinate his animals? If so, against what diseases?
(16) Are there any other means of preventative health care used?
(17) Has the farmer experienced any health problems associated with working under saturated and flooded conditions?

Farmer Perceptions on the Use of Draught Animals in Lowland Rice Production

(1) Does the farmer perceive that there is a potential for the use of draught animals in the lowlands?
(2) Would the use of draught animals in the lowlands conflict with their use in the uplands?
(3) Has the extension service provided information on the use of draught animals in lowland rice production?

Annex B Standard Work Tests

(a) The animal under test is harnessed to a sled via the load cell of an ergometer (Lawrence and Pearson, 1985). The sled is loaded with different weights so that the draught force required to pull it can be varied between W and 5W N where W equals the liveweight of the animal in kg. The animal is encouraged to pull the load for 100 m along a straight track as fast as possible. Each animal is tested at several different loads and in each case the work done and the time required is recorded from the ergometer. Simultaneous measurement of O_2 consumption will also be made. This should be undertaken for at least 20 minutes prior to starting each test and continued after the animal has stopped until the O_2 consumption rate has returned to normal.

(b) A plough or sled is set to provide a draught force equal to 1 to 1.5 W where W is the liveweight of the animal in kg. The animal is harnessed to the implement as described above and encouraged to work as hard as possible for 3 hours. Every five minutes the following data are recorded from the ergometer:

* Work done
* Distance travelled
* Actual working time

Measurements of respiratory volume and O_2 consumption will be made as described in (a) above.

Annex C Background to the Oxylog

The Oxylog which had originally been designed for use with human beings and which has proved reliable in long term field trials and accurate compared with laboratory methods (Harrison *et al*, 1982), is manufactured by P.K. Morgan Ltd, Kent England and uses a turbine flowmeter mounted on the inlet side of the face mask. There are two advantages to having the flowmeter in this position. Firstly it avoids the problem of condensation of water vapour from the animal's breath and secondly using the inlet volume is used to calculate O_2 consumption and hence energy production partially compensates for any inaccuracies caused by changes in RQ. The reason for this is that at low RQ values more O_2 is consumed than CO_2 is produced. This means that the volume of the exhaled air is less than the inhaled air. Using the volume of inhaled air in calculations will therefore overestimate O_2 consumption at low RQs. On the other hand, the use of a constant factor to calculate energy consumption from O_2 consumption leads to an underestimate of energy at low RQs. Using values for the total inflow of air will therefore give more accurate values for energy consumption (Weir, 1949).

After each breath a small reciprocating pump takes samples of air entering and leaving the mask. The samples are passed into separate reservoir/dryers which gives 'running average' O_2 concentrations which are measured using two polarographic O_2 electrodes linked differentially. The electronic system calculates and displays total O_2 consumption and total volume of inspired air at STP, after making corrections for atmospheric temperature, pressure and humidity. Other functions allow the display of O_2 partial pressure difference between the inlet and outlet, and minute volumes of O_2 consumption and airflow. All outputs can be linked to a data logger and recorded automatically.

Several adaptations were necessary in order to use the Oxylog for oxen (Dijkman, 1989). Firstly a mask was made to fit oxen which incorporated a saliva trap and allowed the ox to be guided either by a halter or a nose ring. Initial attempts to seal the mask to the animal's face using foam rubber inside the mask proved unsatisfactory. The present seal consists of an annular cuff of 0.5 mm thick natural rubber which seals perfectly at a point just behind the animal's nose when the mask is pushed onto the face. The basic frame of the mask is made from 10 mm plywood and is of a geometrically simple shape. This means that new masks to fit animals of different sizes can be made quickly, easily and cheaply.

Secondly larger versions of the turbine flowmeter were made. It was found possible to make scaled up versions of this type of flowmeter which gave good linear responses when calibrated using a reciprocating pump operated at different speeds to give a range of flow rates.

The capacity of the inlet and outlet valves was increased simply by increasing their number from one to three and nesting them in a larger tube. Finally the tube connecting the mask to the Oxylog was fitted with a by pass so that only a fraction of the air passed the sampling point.

The ability of the modified system to measure O_2 consumption accurately was checked first of all by displacing a known volume of air through the flowmeter with the reciprocating pump whilst surrounding the O_2 electrodes with a standard gas of known composition. Secondly, the whole system was checked against the standard open circuit system. To do this a cow was fitted with the Oxylog and all the exhaust gases from the mask and Oxylog were passed into the open circuit system. Since the response of the latter to changes in O_2 concentration is relatively slow, each determination lasted for at least 30 minutes. Under these conditions the results from the two methods agreed quite well.

PAPERS PUBLISHED and PRESENTED
DURING PhD PERIOD

paper presented at the Summer meeting of the Nutrition Society, 1993

NUTRITIONAL IMPLICATIONS OF WORK IN DRAUGHT ANIMALS

R. Anne Pearson and Jeroen T. Dijkman
Centre for Tropical Veterinary Medicine
Easter Bush, Roslin
EH25 9RG Midlothian
Scotland

ABSTRACT

The major nutritional need of draught animals is for energy-yielding nutrients to provide the ATP necessary for muscle contraction. Figures for energy requirement are available for horses and ruminants based on laboratory measurements of the energy costs associated with work and measurements of work output in the field. These calorific values are not so readily available for other draught animals. Recent development of techniques which enable the determination of energy expenditure of animals in the field, without relying on laboratory methods, have enabled the energy requirements to be more precisely and widely determined for all the main draught animal species.

The effect of work on the intake and digestion of feeds by draught animals seems to be influenced by feed quality and the physiological state of the animal. Lactating cows can show an increase in feed intake of roughage diets in response to work and horses can do so on good quality diets. However on the poor quality feed that draught animals normally receive, any changes in intake or digestibility associated with work are not sufficient to meet the increased nutrient demand. The importance of improving the staple diets of draught animals using locally available feed resources is emphasised.

The utilisation of nutrients for work and the partition of nutrients within the working cow during lactation are described. The use of cows for draught purposes requires a better quality of diet than that needed for oxen, but may in the long run save farm feed resources because it can eliminate the need to keep draught oxen.

KEYWORDS: *Draught animals, nutrition, work.*

INTRODUCTION

Draught animals have not been used to any great extend in agriculture in the developed countries since the introduction of tractor power in the 1930s and the rapid expansion of agricultural mechanisation over the succeeding decades.

In the third world however, draught animal power continues to make an important contribution to rural and urban economies. In fields where tractors cannot reach, such as terraced hillsides, and on farms where the size and scale of enterprise as well as finance rule out tractors, animal power is the farmers only means of cultivating the land, other than by hand. It is difficult to see farmers replacing animal power by mechanical power in these situations. Indeed some areas of the world have experienced an expansion in the use of animal power over the last two decades. In parts of sub-Saharan Africa for instance, where human power has tended to predominate in agriculture, disease control and prevention measures have now extended the areas in which animals can be kept and they are replacing human power for many of the tasks involved in land cultivation.

Until relatively recently feeding working animals was an empirical business. Only during the last fifteen years have scientists begun to obtain systematic information on the nutritional implications of work on draught animals. One of the main research topics has been to measure energy expenditure of draught animals so that their requirements can be quantified to the same extent as for other classes of livestock. Other investigations have centred on the supply of nutrients to meet these requirements. Ruminants have received the most attention as they are numerically the most important draught animals (Ramaswamy, 1985). Cattle are used on many small farms in Africa, Asia and parts of Latin America. Water buffaloes are important in the more humid areas. Interest in the nutrition of working horses and donkeys, as opposed to the needs of horses in sport, has increased (Fielding and Pearson, 1991). Camels, elephants, mules, yaks, llamas, and some sheep and goats are also used as draught animals in a variety of different operations, from transport and cultivation to harvest operations and water lifting. The nutritional implications of work in these animals is less completely understood than for cattle and buffaloes.

In recent years there has been an increasing move towards the use of cows for work on many smallholder farms (Matthewman, 1987). In areas of constant feed shortage, for example in parts of Bangladesh, females are replacing male work animals, thus removing the need to maintain draught oxen on the farm. In other areas where draught animals are in poor condition at the start of cultivation, for example in parts of southern Africa, female animals are used alongside males to provide sufficient power to enable tasks to be completed on time. Research interest has centred on the partition of nutrients between work, lactation and reproduction, the long term consequences of working draught cows and how best to satisfy their nutritional requirements.

In this paper the effects of work on nutrient requirements, nutrient supply and the consequences for other productive functions are discussed.

NUTRIENT REQUIREMENTS IN WORKING ANIMALS

The major needs of the working animal are for energy-yielding nutrients. Changes in protein requirement associated with work in adult animals seem to be small (Clapperton, 1964: Pearson and Lawrence, 1992). Hence requirements for protein-yielding nutrients are likely to be important only as glucose precursors, through direct oxidation to contribute to ATP production or in their role in enhancing digestion of poor quality roughages.

There is no clinical evidence that significant deficiencies in specific amino-acids, minerals and vitamins occur in draught animals as a result of working over prolonged periods in the year. Work does not appear to affect vitamin and mineral requirements greatly other than a possible increase in the requirements for those minerals associated with the supply of energy to muscles (calcium, magnesium and phosphorus) and the production of saliva and sweat (chloride, sodium). In many places salt is fed to draught animals by farmers to supplement animal feed (Bamualim and Kartiarso, 1985; Gatenby, Pearson and Limbu, 1990; Matthewman and Dijkman, 1993) and counteract the mineral losses during work.

A point often made is that any increased requirement for protein, vitamins and minerals is likely to be met by the extra intake of feed needed to meet the increased demand for energy (Mathers, 1982; Bamualim and Kartiarso, 1985; Lawrence, 1985). In cases where body reserves are mobilized to support the increased metabolism resulting from work, the situation might however be different. Depressed performance due to mineral deficiencies often do not become apparent until a diet is balanced by supplementation and supplements generally help to improve production of all classes of livestock (Winugroho, 1989).

The problem in determining the energy requirement of draught animals has been the difficulty of measuring energy expenditure in animals that are not normally stationary. Brody (1945) suggested increasing maintenance requirements of horses by proportionately 0.1 for each hour of field work. More recently the net energy costs of the various activities which occur during work such as walking, carrying loads, pulling loads and walking uphill and downhill, have been measured in the laboratory for several of the species used for draught purposes: cattle, buffalo, donkeys, camels (Table 1).

If the total work done, distance travelled, height climbed and live weight of the draught animals is then measured in the field the total net energy for work can be estimated (Lawrence and Pearson, 1985; Lawrence and Stibbards, 1990). Using this technique, estimates of the energy requirements of draught animals have been obtained under a range of different circumstances (Lawrence, 1985; Lawrence and Pearson, 1985; Pearson, 1990). The major disadvantage of this technique is that the energy cost of walking has to be assumed. It is not constant but is affected by the condition of the terrain the animal is walking over. The energy costs of pulling loads, carrying loads and walking uphill in the individual species are less of a problem. They remain relatively constant under most working conditions because, apart from the design of the pack saddle, in the case of animals carrying loads, they tend to be unaffected by external influences (Lawrence and Zerbini, 1993).

To solve the problem of extrapolating laboratory measurements to the field situation considerable effort has recently been put into the development of reliable instruments to measure oxygen consumption directly in the field (Dijkman, 1989; Lawrence, Pearson and Dijkman, 1991; Zerbini, Gemeda, O'Neill, Howell and Schroter, 1992). This equipment has enabled energy expenditure to be measured more precisely in animals working under field conditions and hence takes into account the variable factors influencing energy requirements such as ground surface and other environmental factors. It has enabled Dijkman (1993) to measure the energy costs of Bunaji (*Bos indicus*) bulls walking on different surfaces in the sub-humid zone of Nigeria. He found that the animals used up to four times as much energy walking on waterlogged ground compared with walking on dry firm ground (Table 2). The values for walking on firm ground were less than those recorded in oxen walking on treadmills in laboratories (Lawrence and Stibbards, 1990). Zerbini *et al.* (1992) in their field studies also measured energy costs of walking. They reported values for oxen walking on a level soil track about proportionately 0.39 higher than the measurements obtained on treadmills by Lawrence and Stibbards (1990).

Draught animals seem to require more energy for maintenance than non-working animals. Lawrence, Buck and Campbell (1989a) found that the energy expenditure of oxen on a poor quality diet remained higher for up to 17 h after work. Lawrence, Sosa and Campbell (1989b) determined the underlying resting metabolic rate during work, by extrapolating the rate of energy expenditure when oxen worked at different speeds, to zero. They observed that the average 'standing' value was proportionately 0.26 higher than on non-working days. These two observations imply an increase of about 0.1 in net energy for maintenance on days on which oxen work.

NUTRIENT SUPPLY IN WORKING ANIMALS

Supplying draught animals with feed of sufficient quantity and quality at the right time to meet requirements for work is probably the most universal problem farmers keeping draught animals are faced with. The start of the cultivation season is usually the time when feed stocks are at their lowest, particularly in areas where the dry season is long, and yet this is the time when draught animal feed requirements are greatest. The common feeds available to draught animals are the grasses and the cereal crop residues such as maize, millet and sorghum stover and rice straw, fed either on their own in cut-and-carry systems or to supplement grazing when that is available on rangeland, roadsides or field edges. The diets of draught animals are therefore characteristically high in fibre and low in nitrogen with a metabolisability rarely above 0.4 for most of the year. Animals have enough difficulty eating sufficient quantity of these diets to meet their maintenance requirements without meeting any extra demands for work.

This has led scientists to study the effects of work on intake and digestibility of feed by both ruminants and equids. The nature of the diet appears to be a major determinant of the response recorded. In equids, Orton, Hume and Leng (1985) found increases in food intake over resting levels of proportionately 0.02 to 0.27 when horses were exercised at 3.3 m/s (trot) for 1 h per day. Their horses consumed a chopped oaten hay based diet (DM digestibility coefficient of 0.68). On less digestible diets, Pearson and Merritt (1991) failed to record any increase in the intake of donkeys exercised at 1 m/s for 4 h per day. Their animals consumed hay or straw diets with DM digestibility coefficients of 0.55 and 0.47 respectively. Several workers have reported increased digestibility of feed by proportionately 0.06 to 0.20 as a result of light exercise in equids (Olsson and Ruudvere, 1955; Hintz, 1988; Orton et al., 1985; Worth, Fontenot and Meacham, 1987). These diets were of relatively good quality, compared to the diets generally fed to draught animals.

The hypothesis that work may stimulate appetite, because it produces an increase in energy demand, has been more difficult to assess in draught ruminants. Although it may stimulate appetite, this effect may be counteracted by the reduced time available for eating that often occurs on working days. The stress of working, particularly in hot conditions, may also indirectly lower intake by reducing the animal's desire to feed immediately after work. Several researchers have shown similar or reduced intakes of roughage diets by draught ruminants on working days compared with non-working days. Buffaloes in Thailand (Wanapat and Wachirapakorn, 1987), and in Indonesia (Bamualim and Ffoulkes, 1988) consuming rice straw and field grasses, oxen in Nepal consuming rice straw and concentrate supplement (Pearson and Lawrence, 1992) or rice straw and tree fodder (Pearson, 1990) and oxen in Costa Rica consuming poor hay and concentrate supplement did not increase their intake during working periods in response to the increased nutrient demands of work. Animals tended to lose weight. Results of studies where the time of access to feed by both working and non-working animals has been standardised have given conflicting results: Winugroho (1990) reported increased intake by working animals, whereas Bamualim and Ffoulkes (1988) reported little difference. Bakrie, Murray, Hogan, Teleni and Kartiarso (1989) found cattle and buffaloes working for 3 h per day consumed more sorghum hay supplemented with urea and minerals when pulling a loaded cart than when pulling an empty one. No figures were available for resting animals.

Although little increase in intake occurs during working periods, intake in the week immediately after a working period is often higher than in the pre-work week (Pearson and Lawrence, 1992). This suggests either some form of compensatory intake to account for weight loss during work, or that during a working period ruminants may change their feeding behaviour to attempt to compensate for the reduced time available for eating. Evidence for the latter has been provided by a study of feeding behaviour (D.G. Smith, pers. comm.) which showed that draught ruminants increased their rate of eating, rather than changing time spent eating or ruminating to compensate for reduced time of access to feed. That animals showed the same response after a similar period of feed restriction without work, suggested that it was a response to restriction of time available for eating rather than a response to work itself.

A consistent feature of working ruminants seems to be a reduction in the rate of passage of digesta through the gastro-intestinal tract. Ffoulkes, Bamualim and Panggabean (1987) reported reduced rates of passage of chromium III oxide, a non-specific marker, in working buffaloes compared with buffaloes at rest. Pearson and Lawrence (1992) using chromium mordanted hay fibre, a solid particle marker and cobalt-EDTA, a liquid phase marker observed a similar effect in working oxen on a rice straw diet supplemented with some concentrate. This was associated with an increase in apparent digestibility of organic matter in working weeks. However, consistent effects of work on apparent digestibility and gastro-intestinal time are not always seen in oxen (Pearson and Lawrence, 1992) or buffaloes (Bamualim and Ffoulkes, 1988) on fixed dietary allowances.

The studies reported above all refer to the situation in adult male, castrate or non-productive female draught animals. Milking cows seem able to increase intake in response to work even when consuming hay diets. Lawrence and Zerbini (1993) report studies in Ethiopia in which intake of natural pasture hay was greater for working cows (72 MJ ME/d at 90 days post partum) than for non-working cows (60 MJ ME/d at 90 days post partum). Milk production was similar for working and non-working cows, 5 kg/d at 90 days post partum. It was not clear whether the increased intake occurred on all days or whether, as observed in other cattle (Pearson and Lawrence, 1992), the increase occurred in the immediate post work periods. The cows did not work every day but only 50 days in the 90 day period being considered. The increased intake in the working cows was not sufficient to entirely meet the additional energy requirement for work and the cows lost weight.

Taking all the various studies into consideration the general conclusion would seem to be that if draught animals are given almost entirely high fibre roughage diets, low in nitrogen, then the food intake and gastro-intestinal rate of passage of food are both likely to decrease, with the possible exception in draught cows. Changes in digestibility are unlikely to compensate for decreases in intake. Similarly any increase in feed intake in draught cows that does occur is unlikely to be sufficient to entirely meet the additional requirements for work. Hence in order to meet energy requirements for work, to minimise weight loss and maintain work output during the working season, the quality of the ration given to a working draught animal whether it be a cow an ox, a buffalo or a donkey, needs to be improved.

Most working animals lose weight. This can be tolerated if work seasons are short. Weight losses can be made up as quantity and quality of grazing and browse improve on a farm over the rainy season and work demands decrease as crops are sown. However if animals are also used for transport, the work season can extent over most of the year. The working animal then has little or no off season rest period in which to replenish its body reserves. Moreover, with more land taken into crop production in many farming systems as a result of increasing human population pressure, animals in areas with one distinct cropping season are likely to suffer food shortages in the wet season rather than in the dry season. In the dry season there is normally enough bulk food available from crop residues and fallow land, but with grazing areas declining in the wet season the possibility of replenishing body stores can become increasingly difficult. Similarly, cows that are expected to work and produce a calf have little opportunity to gain weight lost during work. In these cases the aim should be to provide enough nutrients in the feed to maintain live weight over the year. From data available on intake and estimates of energy expenditure during work, Lawrence (1990) calculated that if an ox worked an average day of 5.5 h, then it would have to receive a diet with more than 9 MJ/kg DM in order not to lose weight.

UTILISATION OF NUTRIENTS IN WORK AND THEIR PARTITION BETWEEN WORK AND OTHER PRODUCTIVE FUNCTIONS

Measurements of work output and speeds of working in draught animals (e.g. Lawrence 1985; Barton, 1987; Pearson, 1989) and blood lactic acid concentrations (Martin and Teleni, 1989; Pearson and Archibald, 1989) indicate that for most of the time aerobic oxidation of substrates is the dominant pathway for ATP generation when draught animals are working. Studies of substrate utilisation by resting and exercising muscles in equines and in ruminants (Bird, Chandler and Bell, 1981; Teleni, 1984; Oddy, Gooden, Hough, Teleni and Annison, 1985; Pethick, Harman and Chong, 1987; Pethick, Miller and Harman, 1991) have shown that glucose oxidation in muscles is obligatory and long chain fatty acids (LCFA) are the other major fuel. Evidence is also available to suggest that the mobilisation and subsequent contribution to oxidation of LCFA, and ketone bodies, increases as work continues (Rose, Purdue and Hensley, 1977; Pethick, 1984). Equine muscle has a high capacity for glycogen storage (over 126 mmmol/l) which provides considerable glucogenic reserves (McMiken, 1983) and most circulating glucose is absorbed directly from the gut in the horse. In the ruminant glucose availability is limited (Leng, 1970), largely because the ruminant is dependent on hepatic gluconeogenesis of volatile fatty acids to provide most of the circulating glucose and glycogen reserves (Judson, Filsell and Jarrett, 1976). For this reason LCFA are thought to have a particularly important role as energy providers in the ruminants (Teleni and Hogan, 1989).

The uptake of acetate by ruminant muscle is highly diet dependent. High roughage diets encourage the production of acetate in the rumen. Low feed intakes by the animal would result in a low uptake of acetate by the muscle. High feed intakes would be expected to increase acetate uptake by the muscle. This effect does not appear to be exercise dependent (Teleni and Hogan, 1989).

The extent to which amino-acids are oxidised in working muscles of ruminants is less clear, although Teleni and Hogan, (1989) in a study of working buffalo suggest amino-acids are catabolised and used as direct energy sources or as glucose precursors. In a mature male working animal it is probable that if there is a surplus of amino-acids over requirement these will be used as energy-yielding nutrients. However, in lactating animals there is likely to be competition for glucose and glucogenic precursors between work and lactation, which may be detrimental to milk production.

Reports in the literature show a variable effect of work on milk production. Jabbar (1983) in Bangladesh suggested a fall in milk yield when cows are used for draught. Goe (1983) reported that on work days cows can show proportionately a 0.1 to 0.2 decrease in milk yield. Similarly Matthewman (1989) in a series of three experiments with Hereford x Friesian cows in late lactation found that milk yield decreased proportionately by 0.07 to 0.14, depending on diet during exercise equivalent to an energy demand of about 13 MJ per day. Yields of lactose and protein also decreased, but all levels recovered following two days of rest. Yield of milk fat remained unchanged with exercise. The nature of dietary supplement did not seem to have any substantial influence on the impact of exercise on the lactational performance. Intake of a poorly digested forage (straw) in the presence of supplements designed to be 'glucogenic' (based on barley), 'aminogenic' (based on fishmeal), or 'lipogenic' (based on sugarbeet) was not affected by exercise and the nature of the dietary supplement did not seem to have any substantial influence on lactational performance. The main conclusion from these experiments was that the lactating cow deals with a shortage of nutrients created through exercise by restricting secretion of protein and lactose whilst maintaining fat output. It appeared in these cows in late lactation that the nutrient shortage was not overcome by increased intake when the only food available was a poor quality forage.

The picture in early lactation may be a little different. Rizwan-ul-Muqtadir, Ahmad and Ahmad (1975) in Pakistan found no reduction in daily milk production during work. Zerbini (1991) in Ethiopia found that work (4 h/day pulling sledges at an average draught force of 400 N for 4 days a week) did not have a marked effect on milk production, when crossbred dairy cows worked over a period of 90 day, starting two weeks after calving. However he noted that work had a dramatic effect on cow weight loss. Three months after giving birth, working cows had lost an average of 26 kg, whereas non-working cows had lost less than 11 kg. This was despite the fact that working cows increased their intake in an attempt to sustain milk production and meet the energy demands of work (ILCA, 1990, Lawrence and Zerbini, 1993). Over a two year period non-supplemented working cows continued to lose body weight and stopped milk production and reproductive functions in order to perform work. Supplemented working cows were able to perform work and produce milk with an acceptable loss of body weight (Lawrence and Zerbini, 1993).

Excessive weight loss when cows or buffaloes are worked in lactation can result in reduced ovarian activity (Bamualim, Ffoulkes and Fletcher, 1987), reduced conception rates (Jainudeen, 1985) and longer calving intervals (Robinson, 1977; Petheram, Liem, Yayat Priyatna and Mathuridi, 1982).

Clearly if a cow is to be used for work, produce a calf and a good supply of milk then it needs good quality feed. In a study in Costa Rica, cows in mid-lactation needed feed energy equivalent to 2.2 times maintenance to work and maintain milk production (Lawrence, 1985). In virtually all circumstances to achieve an energy intake to meet requirements for work, lactation and maintenance of live weight, supplementation of the basal diet with some concentrates is needed (Zerbini, 1991). In practice many farmers are not able to feed their cows at the level required and will have to accept that if their cows work for a continuous period, they are unlikely to maintain production.

CONCLUSIONS

The major nutritional consequences of work are an increase in the energy requirements of a draught animal, both for work and, it appears at some feeding levels for maintenance. Estimates of energy requirements for work, based on measurements of work output in the field and energy costs of work on treadmills suggest that the extra energy consumption for work are relatively low, up to 1.8 times maintenance for oxen and buffalo. The exceptions may be for large draught horses working for 7 to 8 h a day. Here values of 2.4 times maintenance have been calculated. The development of instruments which allow energy expenditure to be determined in the field will enable the energy requirements of draught animals to be defined more precisely. For instance effects of ambient temperature, implement design and working practice on a draught animals energy requirement can be more clearly quantified using these techniques. The consequences of work and different intensities of work on the resting metabolic rate, both in the short and long term, and effects of level of feeding can be further elucidated. Studies have tended to concentrate on the net energy requirements for work. Heat increment for work is generally assumed to be the same as for maintenance. There is however, no firm experimental proof of this (Lawrence and Zerbini, 1993). This is an area which would seem to require further investigation to aid definition of feeding tables for draught animals.

One of the clear messages to result from investigations of the nutritional implications of work on draught animals, is that although additional nutritional needs may be relatively low, the diets that are available to meet these requirements are usually of poor quality in the areas where most draught animals are found. Many diets barely meet requirements for maintenance let alone any extra requirements for work. The lack of any marked increase in intake, digestibility and utilisation of feed as a result of work, means that in order to meet requirements for work and avoid weight loss, the feed quality needs to be improved. This is particularly true where cows are being used for work.

Considerable attention is now being given locally by scientists to enhance the quality of the diets available to draught animals and other animals on the farms. Emphasis is placed on better storage techniques for the staple feedstuffs, increased conservation of fodder crops, treatment of forage and supplementation with browse in addition to the use of urea and other supplements as they are available. Straight concentrate supplements are very often unavailable or too expensive to consider feeding on small farms other than on those with cash crops and a certain market.

Weight loss clearly has to be accepted in draught animals during the ploughing time at the end of the dry season, and when cows are worked in early lactation. The extent of weight loss that can be tolerated before performance is affected, and the interaction with body condition, are issues which would benefit from further study. Management practices that allow the animal to minimise weight loss and encourage repletion of reserves from feed, without compromising the needs for animal power to produce a crop offer a challenge to the nutritionist, as well as the farmer. Continued investigation of the nutritional implications of work on draught animals would still seem to be appropriate. It seems very likely that animals will continue to provide a considerable proportion of the power on small farms in the foreseeable future.

REFERENCES

ARC (1980). The Nutrient Requirements of Ruminant Livestock. Commonwealth Agricultural Bureaux, Farnham Royal, United Kingdom.

Bakrie, B., Murray, R., M, Hogan, J., P, Teleni, E., & Kartiarso. (1989). Effect of load level on feed utilisation by working cattle and buffalo. D.A.P. Project Bulletin **8**, 23-26.

Bamualim, A., & Ffoulkes, D. (1988). Effect of work and level of feed intake on nutritional parameters and body weight changes of swamp buffalo cows. D.A.P. Project Bulletin **7**, 2-8.

Bamualim, A. and Kartiarso. (1985). Nutrition of draught animals with special reference to Indonesia. In Draught Animal Power for Production (J. W. Copland, editor),.pp. 64-68. ACIAR Proceedings Series No. 10, Canberra, Australia.

Bamualim, A., Ffoulkes, D. and Fletcher, I. C. (1987). Preliminary observations on the effect of work on intake, digestibility, growth and ovarian activity of swamp buffalo cows. DAP Project Bulletin **3**: 6-10.

Barton, D. (1987). Draught power supply, nutrition and the work output of draught animals in Bangladesh. Report prepared for the Ford Foundation, Dhaka and FSRDP. Bangladesh Agricultural University, Mymensingh.

Bird, A.R., Chandler, K.D. and Bell, A.W. (1981). Effects of exercise and plane of nutrition on nutrient utilization by the hind limb of the sheep. Australian Journal of Biological Science **34,**541-550.

Brody, S. (1945). Bio-energetics and Growth. New York: Reinhold Publishing Corporation.

Clapperton, J. L. (1964). The effect of walking upon the utilisation of food by sheep. British Journal of Nutrition **18**, 39-46.

Dijkman, J. T. (1989). The Measurement of Energy Consumption of Draught Oxen in the Field: The Oxylog for Oxen. MSc thesis, Centre for Tropical Veterinary Medicine, University of Edinburgh.

Dijkman, J. T. (1992). A note on the influence of negative gradients on the energy expenditure of donkeys walking, carrying and pulling loads. Animal Production **54**, 153-156.

Dijkman, J. T. (1993). A note on the energy cost of walking in Bunaji bulls. Draught Animal News **18**, 10-14.

Ffoulkes, D., Bamualim, A., & Panggabean, T. (1987). Utilization of fibrous feeds by working buffalo. In Ruminant Feeding Systems Utilizing Fibrous Agricultural Residues (R. M. Dixon editor)- 1986.

Canberra: International Development Program of Australian Universities and Colleges.

Fielding, D., & Pearson, R. A. (1991). Donkeys, Mules and Horses in Tropical Agricultural Development: Proceedings of a Colloquium Organised by the Edinburgh Schoool of Agriculture and the Centre for Tropical Veterinary Medicine of the University of Edinburgh, 3-6 September 1990. University of Edinburgh.

Gatenby, R. M., Pearson, R. A., & Limbu, T. B. (1990). A survey of local and Jersey crossbred draught oxen in the hills of east Nepal (No. 128). PAC Technical Paper Pakhribas Agricultural Centre.

Goe, M. R. (1983). Current status of research on animal traction. World Animal Review **45**:2-17.

Hintz, H. (1988). Effects of exercise on digestibility. Equine Practice **10**, 5-6.

ILCA, (1990). Annual Report and Programme Highlights. Addis Ababa, Ethiopia: ILCA.

Jabbar, M.A. (1983). Effects of draught use of cows on fertility, milk production and consumption. In Maximum livestock Production from minimum Land. (C. H. Davis, T. R. Preston, M, Haque and M. Saadullah editors). James Cook University, Townsville, Australia.

Jainudeen, M. R. (1985). Reproduction in draught animals: Does work affect female fertility? In Draught Animal Power for Production (J. W. Copland editor), pp. 130-133. ACIAR Proceedings No. 10, Canberra, Australia.

Judson, G. J., Filsell, O. H., & Jarrett, I. G. (1976). Glucose and acetate metabolism in sheep at rest and during exercise. Australian Journal of Biological Science **29**, 215-222.

Lawrence, P. R. (1985). A review of the nutrient requirements of draught oxen. In Draught Animal Power for Production. (J. W. Copland editor), pp. 59-63. ACIAR Proceedings Series No. 10, Canberra, Australia.

Lawrence, P. R. (1990). Food energy requirements of draught oxen. In Proceedings of 1st Meeting of the World Association for Transport Animal Welfare Studies (TAW,S). pp. 7-27.

Lawrence, P. R., Buck, S. F., & Campbell, I. (1989). The metabolic rate of oxen after work. Proceedings of the Nutrition Society **48**, 153a.

Lawrence, P. R., & Pearson, R. A. (1985). Factors affecting the measurements of draught force, work output and power of oxen. Journal of Agricultural Science, Cambridge **105**, 703-714.

Lawrence, P. R., Pearson, R. A., & Dijkman, J. T. (1991). Techniques for measuring whole body energy expenditure of working animals - a critical review. In Isotopes and Related Techniques in Animal Production and Health, pp.211-232. Vienna: IAE/FAO.

Lawrence, P. R., Sosa, R., & Campbell, I. (1989). The underlying 'resting' energy consumption of oxen during work. Proceedings of the Nutrition Society **48**, 154a.

Lawrence, P. R., & Stibbards, R. J. (1990). The energy costs of walking, carrying and pulling loads on flat surfaces by Brahman cattle and swamp buffalo. Animal Production **50**, 29-39.

Lawrence, P.R. and Zerbini, E. (1993). Recent trends in research on draught animal nutrition. Paper presented in a Workshop on Human and Draught Animal Power in Crop Production. Harare, Zimbabwe, 19-22 January 1993.(in press)

Leng, R. A. (1970). Formation and production of volatile fatty acids in the rumen. In Physiology of Digesgion and Metabolism in the Ruminant (A. T. Phillipson editor), pp. 406-421. Newcastle upon Tyne: Oriel Press.

Martin, D. G. and Teleni, E. (1989). Fatigue in buffaloes on different work loads. Draught Animal Power Project Bulletin **8**, 2-6.

Mathers, J. C. (1982). Nutrition of draught animals. In Paper Presented to the FAO Expert Consultation on Appropriate Use of Animal Energy in Agriculture in Africa and Asia. Rome: FAO.

Matthewman, R. W. (1987). Role and potential of draught cows in tropical farming systems: a review. Tropical Animal Health and Production **19**, 215-222.

Matthewman, R. W. (1989). The effects of exercise on lactational performance in cattle. Unpublished Ph.D. Dissertation, University of Edinburgh.

Matthewman, R. W., & Dijkman, J. T. (1993). The nutrition of ruminant draught animals. Journal of Agricultural Science, Cambridge. (in press.)

McMiken, D. F. (1983). An energetic basis of equine performance. Equine Veterinary Journal **15**, 123-133.

Oddy, V. H., Gooden, J. M., Hough, G. M., Teleni, E., & Annison, E. F. (1985). Partitioning of nutrients in Merino ewes II glucose utilisation by skeletal muscles, the pregnant uterus and the lactating mamary gland in relation to whole body glucose utilisation. Australian Journal of Biological Science **38**, 95-108.

Olsson, N. and Ruudvere, A. 1955. The nutrition of the horse. Nutrition Abstracts Reviews **25**, 1.

Orton, R. K., Hume, I. D., & Leng, R. A. (1985). Effect of exercise and level of dietary protein in digective function in horses. Equine Veterinary Journal **17**, 386-396.

Pearson, R. A. (1989). A comparison of draught cattle (Bos indicus) and buffaloes (*Bubalus bubalis*) carting loads in hot conditions. Animal Production **49**, 355-363.

Pearson, R. A. (1990). A comparison of the work performance of Jersey crossbred and local oxen in the Koshi hills of east Nepal (No. 130). PAC Technical Paper Pakhribas Agricultural Centre.

Pearson, R. A., & Archibald, R. F. (1989). Biochemical and haematological changes associated with short periods of work in draught oxen. Animal Production **48**, 375-384.

Pearson, R. A., & Lawrence, P. R. (1992). Intake, digestion, gastro-intestinal transit time and nitrogen balance in working oxen: studies in Costa Rica and Nepal. Animal Production **55**, 361-370.

Pearson, R. A., & Merritt, J. B. (1991). Intake, digestion and gastrointestinal transit time in resting donkeys and ponies and exercised donkeys given ad libitum hay and straw diets. Equine Veterinary Journal **23**, 339-343.

Petheram, R. J., Liem, C., Priyatman, Y. and Mathuridi.(1982). Village buffalo fertility study, Serang District of West Java. Research Institute for Animal Production, Bogor, Indonesia. Report No. 1.

Pethick, D. (1984). Energy metabolism of skeletal muscle. In Ruminant Physiology - Concepts and Consequences. Proceedings of a Symposium, pp. 227-287. Perth, University of Western Australia.

Pethick, D. W., Miller, C.B. and Harman, N.G. (1991). Exercise in Merino sheep - the relationship between work intensity, endurance, anaerobic threshold and glucose metabolism. Australian Journal of Agricuitural Research **42**, 4, 599-620.

Pethick,D. W., Harman, N. and Chong, J. K. (1987). Non-esterified long-chain fatty acid metabolism in fed sheep at rest and during exercise. Australian Journal of Biological Science **4,** 221-234.

Ramaswamy, N. S. (1985). Draught animals power - its socio-economic impacts. Asian Livestock **10**, 99-107.

Rizwan-ul-Maqtadir, R.A.G., Ahmad, M. and Ahmad, Z. (1975). Draught power and its effect on milk yield and milk composition in lactating buffaloes during winter season. Pakistan Journal of Agricultural Science **12**, 93-98.

Robinson, D. W. (1977). Centre Report Livestock in Indonesia. Centre for Animal Research and Development, Bogor, Indonesia.

Rose, R.J., Evans, D. L., Knight, P. K., Henckel, P., Cluer, D. and Saltin, B. (1992). Muscle fibre types, fibre recruitment and oxygen uptake during exercise in the racing camel. In Proceedings of the First International Camel Conference (W. R. Allen, A. J. Higgins, I. G. Mayhew, D. H. Snow and J. F. Wade editors), pp. 219-222. R & W Publications Ltd., New Market.

Rose, R. J., Purdue, R. A. and Hensley, W. 1977. Plasma biochemistry alternations in horses during an endurance ride. Equine Veterinary Journal **9**, 122.

Teleni, E. and Hogan, J.P. (1989). Nutrition of draught animals. In Draught Animals in Rural Development. (D. Hoffman, J. Nari and R. J. Petheram editors), pp. 118-133. ACIAR Proceedings Series No. 27, Canberra, Australia.

Teleni, E. (1984). Muscle Metabolism in Ruminants. PhD thesis. University of Sydney.

Thomas, C. K. and Pearson, R. A. (1986). Effect of head cooling on energy expenditure, feed intake and heat tolerance of Brahman and Brahman x Friesian cattle working on treadmills. Animal Production **43**, 83-90.

Wanapat, M. and Wachirapakorn, C. (1987). Effects of walking on feed intake and digestibility of rice straw by water buffaloes. In Proceedings of the Fourth AAAP Animal Science Congres, pp.332. Hamilton, New Zealand.

Winugroho, M. (1989). Mineral supplementation to working buffalo and cattle grazed on field grasses in Subang, West Java. Draught Animal Power Project Bulletin **9**: 19.

Winugroho, M. (1990). The effect of work durations on voluntary feed intake and digestibility, liveweights and physiology of buffaloes fed a grass:rice straw diet. In Proceedings of the Sixth Congress of the Federation of Asian Veterinary Associations (FAVA), October 16-19, 1988, Denpasar, Bali.

Worth, N. J., Fontenot, J. P., & Meacham, T. N. (1987). Nutritional and physiological effects of exercise in the equine. Animal Science Research Report-Virginia Agricultural Experimental Station **6**, 79-81.

Zerbini, E. (1991). Cow traction - what about milk and calves? ILCA Newsletter **10**: 1, 5.

Zerbini, E., Gemeda, D.H., O'Neil, D.H., Howell, P.J. and Schroter, R.C. (1992). Relationships between cardio-respiratory parameters and draught work output in F1 crossbred dairy cows under field conditions. Animal Production **55**, 1-10.

Table I :Published values for energy expenditure for walking and working in draught animals and for the efficiency of doing work.

Activity	Energy Expenditure Average Value	Animal(s)	Author(s)
Walking (J/m per kg live weight)	1.9	Cattle (*Bos taurus*)	Brody (1945)
	2.1	Brahman cattle/ Water buffaloes	Lawrence and Stibbards (1990)
	0.97	Donkeys	Dijkman (1992)
	2.0	Camels	Rose et al (1992)
Carrying loads (J/m per kg carried)	2.6	Brahman cattle	Lawrence and Stibbards (1990)
	4.2	Water buffaloes	
	1.1	Donkeys	Dijkman (1992)
Efficiency of doing work pulling loads (work done/ energy used)	0.30	Brahman cattle	Lawrence and Stibbards (1990)
	0.37	Buffaloes	
	0.38	Donkeys	Dijkman (1992)
Efficiency of doing work raising body weight (work done/ energy used)	0.36	Brahman cattle and Brahman x Friesian cattle	Thomas and Pearson (1986)
	0.35	Cattle	ARC (1980)
Walking downhill (J/m per kg live weight) -10 %	0.55	Donkeys	Dijkman (1992)
-15 %	0.67	Donkeys	Dijkman (1992)

TABLE II

The energy cost and speed of walking of Bunaji draught bulls on soils of different consistency in the sub-humid zone of Nigeria.

Soil	n	Average energy for walking E_w (J/m per kg)	s.e.	Statistical significance of difference	Average walking speed (m/s)	s.e.	Statistical significance of difference
Unploughed upland	38	1.47a	0.03	***	0.97a	0.08	**
Ploughed upland	17	2.87c	0.10		0.83bc	0.08	
Unploughed dry fadama	13	1.76b	0.07	***	0.87bc	0.05	**
Ploughed dry fadama	15	3.76d	0.32		0.74d	0.05	
Unploughed wet fadama	19	3.30d	0.14	***	0.80b	0.04	***
Ploughed wet fadama	18	8.58e	0.53		0.65e	0.06	

Paper in press. : Journal of Agricultural Science (Cam.)

THE NUTRITION OF RUMINANT DRAUGHT ANIMALS

R.W. Matthewman and J.T. Dijkman

Centre for Tropical Veterinary Medicine,
University of Edinburgh, Easter Bush, Roslin,
Midlothian, EH25 9RG, Scotland

Short Title: Draught animal nutrition

1993

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R.W. Matthewman and J.T. Dijkman

Centre for Tropical Veterinary Medicine,
University of Edinburgh, Easter Bush, Roslin,
Midlothian, EH25 9RG, Scotland

INTRODUCTION

Cattle and buffaloes provide the power for cultivation and transport in many countries and are a major element of agriculture on a world scale, particularly in the tropics. The effects of work and exercise on physiological and metabolic functions are many, but less is known about the effects in draught cattle than in horses (Pearson & Archibald 1989). Nutrient requirements for maintenance, growth, lactation and growth of concepta in ruminants have been relatively well researched and documented, but requirements for work and the partition of nutrients in working ruminant animals are less well understood.

Ruminant diets in the tropics are usually based on fresh roughage, crop residues and by-products; concentrate foods are not used to any great extent. Such diets often do not provide balanced nutrient intakes and food intake as a whole may be restricted because of low digestibility and the effect of work itself. As a result, normal diets may provide the animal with only maintenance requirements and the additional energy expenditure for working may cause animals to lose weight. In order to match requirements of draught animals with feed resources, it is important to incorporate what is presently known into feeding practice. Some uncertainties still exist and require further investigation.

A number of reviews of draught animal nutrition have been carried out. The dietary energy and nutrient requirements for draught ruminants and methods of calculating needs have been examined by Mathers (1984), Pearson (1986) and Lawrence (1985, 1987*a*, 1988). In addition to other aspects, Teleni & Hogan (1989) considered the nutrient requirements of female draught animals. Ffoulkes & Bamualim (1989) considered the utilization of tropical feedstuffs for draught animals. Local reviews have also been carried out, such as those of draught animal feeding in Indonesia (Bamualim & Kartiarso 1985), Sri Lanka (Ibrahim 1985), Thailand (Wanapat 1985) and Bangladesh (Barton 1987). The bibliographic database prepared by Starkey *et al.* (1991) contains over forty citations under the heading 'Nutrition and Feeding of Draught Animals', with other nutrition related citations under the headings of 'Management and Training' and 'Physiology of Work and Energy Expenditure'. This database indicates the relatively limited attention which the subject has received.

The present review considers the work capacity of draught animals, their energy, protein, mineral, vitamin and water requirements, the influence of work on food intake, digestion and body weight, and energy partition for work. The implications for feeding draught animals are discussed.

WORK OUTPUT OF DRAUGHT RUMINANTS

The available tractive effort (kg force) of draught animals is mainly a function of body weight. Tractive efforts are reported to range from 10 to 14% of body weight at speeds of 0.7 to 1.1m/s (Goe 1983). Maximum efforts over short periods may be four times as great as average tractive effort (Munzinger 1982). Size may vary greatly between breeds. A typical draught bovine used in Bangladesh for example, is small, generally in the range of 200 - 250 kg in the case of bullocks and 160 - 170 kg for cows (Gill 1981). Water buffaloes on the other hand, can easily reach mature body weights over 700 kg.

FAO (1982) suggested that tractive effort over 8 - 10 % of bodyweight with animals travelling at a speed of 0.8 m/s generates excessive stress on an animal. In our own observations on Fulani bulls in Nigeria (J.T. Dijkman, unpublished) animals often developed tractive efforts of 12 to 15 % of body weight at a speed of 0.5 to 0.9 m/s for more than 3 h, without showing signs of distress or unwillingness to work.

Actual work output (J) during the working day is variable and dependent on numerous factors such as the ploughman, ground and soil conditions (Pearson *et al.* 1989). Other factors which could play a role are the health and nutritional status of the animals. Swamp buffaloes in SE Asia work for up to 5 h a day for *c.* 2 - 4 months a year during May to September (Chantalakhana 1981), but the length of the working season depends on the region and farming system (Buranamanos 1963).

ENERGY REQUIREMENTS

In parallel with research on energy expenditure, much research has been carried out to determine methods of measuring energy expenditure. This will not be reported here, but the important contribution which the development of suitable instrumentation has made to the elucidation of energy expenditure is acknowledged.

The energy expenditures required for the tasks that ruminant draught animals perform have been established by several workers (Hall & Brody 1934; Brody 1945; Ribeiro *et al.* 1977; King 1983; Lawrence & Stibbards 1990). The commonly accepted energetic values, over and above maintenance (and growth, pregnancy or lactation if applicable), for walking, carrying, vertical locomotion and the efficiency of mechanical work, are shown in Table 1.

Table 1 Near Here

Most of the values shown in Table 1 were obtained while animals were walking and working on a treadmill or in a circular race, by measuring their gaseous exchange. Such animals are trained to walk without straining against their harness or tether. These values are in net energy (NE). Expenditure is sometimes quoted in terms of metabolizable energy (ME) and care should be taken to ensure that the type of energy is known and stipulated in calculations. The values obtained have subsequently been used in factorial estimations of the NE expenditure of animals working in the field (Mathers 1984; Graham 1985; Mathers *et al.* 1985; Lawrence 1985, 1987*a*).

The NE used for work has a number of components:

NE used for work = energy for walking (AFM)
+ energy for carrying loads (BFL)
+ energy for pulling loads (W/C)
+ energy for walking uphill((9.81HM)/D)

This can be expressed as

$$E = AFM + BFL + (W \quad C) + (9.81HM \quad D)$$

Where: E = NE used for work (kJ); A = energy used to move 1 kg of body weight 1 m horizontally (J); F = distance travelled (km); M = liveweight (kg); B = energy used to move 1 kg of applied load 1 m horizontally (J); L = load carried (kg); W = work done whilst pulling loads (kJ); H = distance moved vertically (km); C = efficiency of mechanical work = work done energy used; D = efficiency of raising body weight = work done raising body weight energy used and 9.81 = gravitational constant.

NB. Energy used is the total energy expended for an activity by the animal; work done is less than the energy used because of inefficiencies.

The values M, L and H can be determined routinely. Values F and W can be measured throughout the working day using apparatus such as those developed at the Centre for Tropical Veterinary Medicine (Lawrence & Pearson 1985). The result of the factorial equation is divided by the efficiency of utilization of ME (k_m) for maintenance, to arrive at the extra ME required for work.

Results of research recently carried out in Nigeria (J.T.

Dijkman, unpublished), where the oxygen consumption of well fed Fulani bulls was measured using a modified Oxylog (Dijkman 1989; Lawrence & Dijkman, in press), showed results for the efficiency of doing work similar to those in Table 1. The net energy expenditure for walking varied according to the consistency of the soil. Values ranged from 1.5 J/m per kg liveweight on firm upland soils to 3.3 J/m per kg liveweight on inundated lowland soils. After ploughing, the energy expenditure for walking on the respective soils more than doubled. This implies that when animals are ploughing in pairs, the lead ox (i.e. the one walking on the soil which has already been ploughed) will use *c.* 25 % more energy during the working day than the other animal in the pair. The influence of walking in mud on the energy expenditure for locomotion had been reported earlier by Lawrence (1987*b*). These results, plus the influence of the positioning of saddles (Lawrence & Stibbards 1990) and downhill gradients (Dijkman 1992) further require that careful consideration has to be given to the conditions in which animals work before calculations of energy expenditure, using a factorial method, are carried out. Dijkman's research on downhill gradients was carried out with donkeys and the energy expenditure of cattle walking downhill has not been determined.

It has been accepted that estimating the energy expenditure of draught animals as 2.7 times the maintenance expenditure (FAO 1972; Goe & McDowell 1980) is an over-estimation and that values between 1.3 and 1.8 times maintenance (Lawrence 1985; Barton 1987; Pearson 1988) are probably a better reflection of the real energy expenditure.

USE OF THE METABOLIZABLE ENERGY (ME) SYSTEM FOR DRAUGHT ANIMALS

Lawrence (1985) considered that maintenance ME requirements of draught animals can be assumed to be the same as for non-working animals and that ME is used with the same efficiency for maintenance and work. This argument was based on the assertion that the heat increment associated with work is the same as for maintenance, since in both cases it is produced mainly as a result of converting the ME in the diet to the correct form for fuelling muscle tissue, albeit at a higher rate than in the non-working animal. This argument is not strictly true, since during exercise there is a pronounced shift in the metabolites used to fuel muscle tissue (Bird *et al.* 1981; Pethick 1984; Preston & Leng 1987), which could influence the efficiency of use of ME. In addition, not all ME is used by muscle. Standing metabolic rate on working days shows a pronounced increase over and above resting metabolism (Lawrence *et al.* 1989*a*). This has important implications when calculations of the total energy expenditure are made.

Further work by Lawrence *et al.* (1989*b*) indicated that animals fed below maintenance showed a significant increase in resting metabolic rate for up to 16 h after work as compared to resting metabolic rate on non-working days, whereas in well fed animals no such increase was measured. The explanation given for this phenomenon was that animals are resynthesising the reserves used during work. On the described diet however, there would have been no metabolites available to restore body reserves and it is more likely that body reserves were redistributed since the animals were in a good condition at the start of the experiment. Nevertheless, the observation is an important one and further investigation the effect of body condition on this phenomenom is required.

Martin & Teleni (1989) suggest that the reliance of untrained animals on anaerobic metabolism renders them less efficient users of ME. Work carried out by Teleni & Pieterson (1989) shows that this reduction amounts to *c*. 6 %.

An adaptation to hot environments is to reduce thyroxine output, which in turn reduces metabolic rate. It could be hypothesised that *Bos indicus* cattle have lower metabolic rates *per se* than *Bos taurus* cattle. Work on cattle by Frisch & Vercoe (1969, 1977) and Vercoe (1970*a,b*) seems to support this hypothesis, whereas work carried out on sheep by Blaxter *et al* (1966) is less conclusive.

The scarcity of conclusive data about *Bos indicus* cattle working in warm climates led Graham (1985) to conclude that feeding draught animals can only be done on an *ad hoc* basis. However, with the development of reliable equipment for the measurement of energy expenditure in the field (Dijkman 1989; Clar 1991; Zerbini *et al.*

1992) more field data on *Bos indicus* cattle will become available and calculations of energy requirement can be adjusted accordingly. Moreover, any disadvantages of using the ME system (and the associated metabolizable protein system) for tropical animals on poor diets are outweighed by the greater accuracy of this over other systems.

PROTEIN REQUIREMENTS

Increases in daily amino acid requirements for muscle growth and development during work are likely to be small (Pearson 1986). If part of the increased energy requirements for work are met by protein sources, this would represent an increase in protein requirements resulting from work. Lawrence (1985) conducted experiments in Costa Rica in which work had no significant influence on protein requirements. No information is available to indicate whether obligatory nitrogen losses increase during work, although one would expect this. Webster & Wilson (1980) suggest that an additional 13.5 g of digestible protein is required for each hour worked. In agreement with Lawrence (1985), they state that these extra requirements will be covered by the extra intake of food needed to supply the increased energy needs.

Recent studies which indicate that draught animals fed on poor quality diets cannot increase their food intake when they work (Barton 1987; Ffoulkes *et al.* 1987; Henning 1987; Bakrie *et al.* 1988; Bamualim & Ffoulkes 1988; Pearson 1990), suggest that work may result in the catabolism of body protein to meet energy requirements, resulting in an overall protein/nitrogen deficit.

Protein is likely to have an important role in ATP production (Teleni & Hogan 1989), through direct oxidation, as a glucose precursor or through its stimulatory role in digestion. The last would result in increased availability of nutrients to animals on poor diets. Amino acids are likely to be used for energy yielding purposes when the demand for energy increases relative to the demand for protein during work, or if the proportions of amino acids are not compatible with protein synthesis. In working animals which are not gaining weight, absorbed amino acids will be metabolized (largely in the liver) to give rise to acetate, ketone bodies or glucose precursors (Preston & Leng 1987).

The differential changes in requirements for energy and protein when ruminants work, imply that the ratio of required dietary protein (or nitrogen) energy will change accordingly, with an increased demand for energy relative to protein. In practice, in most diets based on low digestibility roughages, the growth of rumen organisms is limited by the concentration of ammonia in the rumen fluid. Under these circumstances, a simple N source could stimulate intake to meet energy demands. The important point is to strike the balance between soluble carbohydrate and ammonia to ensure optimal rumen function.

MINERAL AND VITAMIN REQUIREMENTS

There seems to be no clear evidence that work significantly affects mineral and vitamin requirements and further research into this area is required. Agarwal *et al.* (1982), however, reported a decrease in blood magnesium (and phosphorus in some animals) in working buffalo. These reductions may be related to the increased use of both minerals in the processes associated with increased energy metabolism during exerecise. Decreased blood phosphorus concentrations in exercising ruminants may be an attempt to re-establish intracellular phosphate reserves or may result from increased carbohydrate metabolism in response to exercise (Codazza *et al.* 1974). If a diet is sufficient and balanced for minerals during normal metabolism, then one would expect that during an increase of metabolism, the diet would be capable of supplying the extra energy required. In cases where body reserves are mobilized to support the increased metabolism resulting from work, the situation might be different. Mineral deficiencies often do not become apparent until a diet is balanced by supplementation and supplements generally help to improve production of all classes of livestock (Winugroho 1989).

Moreover, in hot climates, as the intensity of work increases, salt losses resulting from sweating will have to be replaced, especially because forage crops tend to be very low in sodium in certain areas.

WATER REQUIREMENTS

There is no information on the precise increase in water requirements resulting from work in draught animals. Further research is required on this topic. Ruminant animals acquire water in three ways; voluntary water intake, water taken in via feed and the water produced by metabolic oxidation (ARC 1980). Requirements are related to heat load, growth, milk production and loss of salts and nitrogenous end products in faeces and urine (Louw 1984). Cattle need more water on high protein and mineral diets, resulting in a greater urine output. Marked reductions in both milk production and feed intake occur when cattle are restricted in their water intake (English 1966; Little *et al.* 1976) and these will be exacerbated by work. Water restriction may improve digestibility owing to the increased retention time in the rumen (Brosh *et al.* 1986). On balance there seems to be no advantage in restricting water intake and it normally appears to be well controlled by requirements. The high positive correlation between free choice intake of feed dry matter and water should be utilized to the full.

EFFECT OF EXERCISE ON VOLUNTARY FOOD INTAKE

The diets of tropical draught animals often consist mainly of natural pasture and vegetation supplemented with cereal grains, crop residues and by-products. Meeting increased energy demands on such diets would be facilitated if working animals could increase their food intake. Provided the chemical and physical properties of the food do not impose limitations, ruminants should be able to increase their intake in a similar way to monogastric animals (Weston 1985). The food intake of working cattle or buffaloes can be limited both by the poor quality of feeds available (i.e. high fibre and low nitrogen contents) and by the reduced time available for feeding and rumination during the time when animals work.

Light to medium work has been shown to increase voluntary feed intake in horses and rats, but the situation was reported to be unclear in draught animals (Weston 1985). Since then, numerous workers have investigated this topic. Some authors have found no increases in the intake of poor quality roughage in working animals (Barton 1987; Ffoulkes *et al.* 1987; Henning 1987; Bakrie *et al.* 1988; Bamualim & Ffoulkes 1988; Pearson 1990). Other authors (Winugroho 1988; Wachirapakorn & Wanapat 1989; Bakrie *et al.* 1989) have found that working animals have a greater food intake than non-working control animals.

Barton (1987) fed oxen on either urea-treated or untreated rice straw supplemented with 1kg fresh grass over a 7-week working period and found that exercise did not increase food intake. Henning (1987) failed to demonstrate increased food intake or rumen fill in sheep exercised on treadmills for up to 9 km/day, over 3h/day for 14 days. In Nepal, Pearson (1990) found that when oxen were exercised they ate less and lost weight.

In contrast, Ffoulkes (1986) and Winugroho (1988) found that work increased intake of coarse roughage (rice straw) and fresh grass. Ffoulkes (1986) fed 16 buffalo cows on a 1:1 mix of coarsely chopped rice straw and natural pasture grass and found that work increased intake by an equivalent of 9.8 MJ ME/day. Similarly, Winugroho (1988) found a 25% increase in food intake in 16 buffalo cows which pulled an 85kg sled for 0h, 3h or 6h/day over a 39 day period and were fed on a 1:1 diet of chopped fresh roadside grass and rice straw. Ffoulkes *et al.* (1987) concluded from their work, in which walking buffaloes ate 7% more poor quality roughage and in which digestibility increased from 46.9 to 52.9%, that if these were true effects of exercise then the point at which tissue building nutrients are utilized as energy sources for prolonged muscular activity will be delayed by the greater availability of nutrients from the diet when animals exercise or work.

The time spent working may not interfere with food intake. In his experiments, Henning (1987) cited evidence from grazing animals to support this supposition. Animals eating poorer quality roughage however, may respond differently from grazing animals. Pearson (1990) considered that food intake is more likely to decrease in working animals fed on bulky diets, as work restricts the time available for feeding. Animals may work harder and longer in reality than under experimental conditions and the effects on food intake should not be under-estimated.

EFFECT OF EXERCISE ON RUMEN FERMENTATION AND DIGESTION

Linked to the effect on food intake is the effect on digestive functions. Some evidence suggests a positive effect (Ffoulkes 1986; Winugroho 1988), whereas other evidence suggests the contrary (Kibet & Hansen 1985; Henning 1987; Pearson 1990). Numerous authors have suggested that exercise may act as a physical stimulus to movement of digesta and may cause mixing of rumen and gut contents, which may aid passage through the tract. Relatively light exercise may have a beneficial effect on digestive function by causing a greater mixing of the rumen contents, which may enhance microbial fermentation. At higher levels of work and exercise, more detrimental effects may be seen. It might be expected that higher work levels would cause a shift of blood supply from the gut to muscles and peripheral tissues.

Rumen stability can be maintained through frequent feeding. If animals are fed once a day, the nutrient supply to the microbes is likely to become exhausted, hence causing lysis of microbes and a slower rumen fermentation (Ffoulkes & Bamualim 1989). Interruptions and reduced frequency of feeding resulting from work may have similar effects.

Ffoulkes (1986) reported a 0.13 increase ($P<0.05$) in digestibility in working buffaloes which received 100% of requirement. Animals on a restricted diet (75%) showed a decrease in digestibility, in agreement with Astatke *et al.* (1986), who found that DM digestibility was higher (0.58 compared with 0.40) in working cattle in Ethiopia fed to requirement (maintenance plus 5h work), than in animals on a restricted (75%) diet. Ffoulkes *et al.*, (1987) found that walking buffaloes ate 7% more poor quality roughage ($P<0.1$) and that digestibility increased from 46.9 to 52.9% ($P<0.05$). Winugroho (1988) reported an increase from 0.38 to 0.50 in digestibility in working buffaloes compared with non-working buffaloes. Kibet & Hansen (1985) in Kenya gave four forages to three steers (two Boran and one Sahiwal) which walked for 0, 1 or 10km/day to investigate the dry matter digestibility (DMD) of roughages in nylon bags suspended in the rumen and found that rumen DMD was not influenced by exercise and distance walked. Digestibility was 0.47 (0km), 0.49 (1km) and 0.46 (10km). There is no indication that work and exercise affect digestion in the intestine.

The available results are thus inconclusive about the effect of work on digestibility and food intake. More research is needed.

EFFECT OF EXERCISE ON BODY WEIGHT

Loss of weight in working animals has been reported by numerous authors. Astatke *et al.*, (1986), not surprisingly, found that both feed restricted animals and animals fed to 100% of maintenance requirement lost weight (between 0.04 - 0.17) when working for 5 h daily over a 23 week period. Female buffaloes (Winugroho 1988) and working non-pregnant buffaloes in Indonesia (Ffoulkes 1986) lost weight when they walked. These authors concluded that even on a restricted diet of rice straw and grass, non-working animals could maintain themselves and gain weight, but that working animals require a better diet to avoid weight loss. Feeding strategies involving supplementation should aim to provide some nutrients that are non-fermentable and which are digested in the small intestine. Weight changes have been attributed by these authors to tissue gain or loss. They did not discuss the possible effects on weight changes of changes in gut-fill and the rate of passage of digesta resulting from exercise. Cows which were exercised for 3h/day for 3 weeks were found to lose weight (R.W. Matthewman, unpublished), but this was replaced in the subsequent 3 weeks at a significantly ($P<0.001$) greater rate of weight gain than in the period before working. This suggests that the weight loss when exercising was in part the result of loss of gut fill which was replaced when the animals stopped walking. There is no reason why under some circumstances weight loss in draught animals should not be accepted in the same way that it is accepted that dairy animals will 'milk off their backs' in the early stages of lactation. In order for dairy animals to be able to do this, they should be well fed and in good body condition prior to parturition.

EFFECT OF BODY CONDITION ON WORK OUTPUT

The fact that draught animals in many tropical countries tend to be in the poorest condition when they are most needed for work, is widely perceived as a major problem (Smith 1981). Supplementation during the dry season is normally advised in preparation for work during the early rains which is crucial for timely ploughing and sowing. Studies carried out in Mali by ILCA (1990) seem to contradict this, as neither the animals' body weight nor condition had a noticeable effect on work output. Animals that had lost up to one fifth of their body weight in the dry season, performed as much work as those in good condition, albeit at a slower rate.

Using draught animals in this way is possible if animals are expected to produce only traction and when they are allowed to regain their lost weight immediately after the working period (Matthewman *et al.* in press). If animals are used in an all-year-round cropping system, with resting periods that would not allow for total replenishment, it is important that animals are fed to maintain liveweight. Earlier discussions about food intake and weight loss during work imply that the only way to achieve this would be to feed better quality diets than those normally available.

With more land taken into crop production in many farming systems as a result of increasing human population pressure, animals in areas with one distinct cropping season are likely to suffer food shortages in the wet season rather than in the dry season. In the dry season there is normally enough bulk food available from crop residues and fallow land, but with grazing areas declining in the wet season the possibility of replenishing body stores can become increasingly difficult.

FEEDING DRAUGHT ANIMALS

The extra nutritional requirements for work in any ruminant draught animal are obviously case-specific. Animals may work 4-5 h/day in cultivation activities over periods of a few weeks or longer periods of months during the cropping seasons. Carting may occur year round. Careful application of a factorial method should provide an easy estimation of the nutritional requirements for such work expenditure. With field data becoming increasingly available, it seems likely that the accuracy of this method will improve. Work increases an animal's requirements for LCFAs and glucose. The need for specific metabolites is particularly important in dual or triple purpose animals. Draught cows might benefit from diets which increase glucose precursors such as high starch diets, but work carried out in Edinburgh was not able to demonstrate this using five diets fed to cows which walked up to 10 km a day (R.W. Matthewman, unpublished).

Whereas work does not seem to pose great demands for amino acids in animals which are in good condition, which cannot increase food intake and which may catabolize body protein as an energy source, a protein supplement would help to increase food intake and balance protein deficit. As a general rule, fermentable protein stimulates intake and digestion on low quality roughages and as such plays a very important role.

There is no evidence that work significantly affects vitamin requirements, but there is some evidence that work can reduce blood levels of minerals such as Mg and P (Agarwal *et al.* 1982). Winugroho (1989) reported a 90% increase in liveweight gain in weaners, 28% in lactating cows and 76% in working cattle given a mineral supplement. Water intake is important at all times, and working animals have increased needs. In dry areas, this might be a further problem which would exacerbate reduced feed intakes.

The timing of feeding during the day and the number of feeds when animals are working, should allow the animal to consume as much food as possible. Many questions remain in this specific area, but food intake is likely to be restricted by the quality of the feed and delayed passage through the tract. Results of research on food intake of draught animals suggest the need for diets of increased quality, rather than greater intake of the same diets. If animals cannot increase the intake of poor quality food when they work, then requirements will have to be met from better quality diets. Animals might increase intake of better quality diets when they work and it is possible that the increase in quality might not need to be great to achieve the increased nutrient intake required. Optimizing intake by manipulation of roughages or provision of supplements to maximize the efficiency of rumen fermentation often require extra inputs which the resources available to a farmer might not allow.

In areas where grazing is abundant, the appropriate strategy would be to have more animals doing what little work they can. Animal use will have to be specialized unless supplementary feed is available.

In areas where land is scarce, the appropriate strategy would be to use fewer, multipurpose animals, so that available food resources can be channelled through fewer animals, resulting in a more efficient utilization of food resources on small farms.

Working animals can expend up to 1.8 times the maintenance energy requirement. Hence for a 300kg animal, this is approximately an additional 25MJ ME/day or a total of 55MJ ME/day. Assuming that a non-lactating animal could eat 5.5kg dry matter (DM) a day [DMI ($g/W^{0.73}$ = 106.5q + 24.1, where W = body weight (kg), q = ME/GE (GE = 18.5 MJ/kgDM); NE for maintenance = $0.36W^{0.73}$; heat increment for maintenance (and work) = (0.497 − 0.019 M/D)NE_m (NE_m = net energy for maintenance; M/D = energy concentration in DM); MAFF 1984], this would require an M/D of 10.5 MJ ME/kgDM. To achieve this energy intake the animal would have to eat a diet including good quality fresh grass in addition to poor quality roughage. This would be possible in the early wet season, particularly if the farmer cut-and-carried fodder. A 300kg working, lactating animal producing 5 kg milk per day would require approximately an extra 25 MJ ME/day. The M/D would have to be between 12.5 and 13 MJ ME/kgDM assuming that the DM intake was 6kg/day. This animal would need to be fed on a diet of good grass with some concentrate supplementation. This is summarized in the estimations of ME requirements and food intakes shown in Table 2, which indicate the importance of diet quality to achieve the necessary DMI to support energy expenditure during work.

These estimations do not consider protein requirements, which would further complicate the calculation. It is unlikely that a lactating cow would be fed on a diet of sufficient quality to support work and lactation, or that such an animal could eat enough dry matter during the working day to meet requirements. Its milk yield would be reduced as a result. Protein and nitrogen deficiencies in the diets might result in catabolism of body tissues, which would have further negative consequences for the animals.

It is not possible at present to give the precise energy requirements for individual work activities such as ploughing or pulling a cart. Ploughing soil A for 2 h is not equal to ploughing soil B for 2 h. Information from some of the experimention cited earlier, however, is increasing our ability to make closer estimations for specific types of work.

Reports by ILCA (1990) imply that neither the animals' body weight nor their condition have a noticeable effect on work output. Interpretation of these results should carefully be considered and is likely to be country and even region specific. Although there might be no direct influence of body condition on work output, animals would still have to be allowed to regain their lost condition immediately after the working period. In areas where animals do not have time to replenish body reserves because they are worked throughout the year, the emphasis must be on the maintenance of body weight by providing better diets.

Many questions concerning the feeding of draught animals have been answered over the past 10 years and our understanding of nutritional requirements has improved greatly. Nevertheless, research to find the key factors which control food intake and to determine supplements to correct nutrient imbalances needs to continue. Cheap and practical ways to improve draught animal feeding and appropriate and low cost feeding strategies need to be developed *in situ* to optimize the use and efficiency of the available feedstuffs.

REFERENCES

Agarwal, S.P., Singh, N., Agarwal, V.K. & Dwaraknath, P.K. (1982). Effects of exercise on serum electrolytes and their relationship in entire, castrated and vasectomised male buffaloes. *Indian Veterinary Journal* 59, 181-184.

Agricultural Research Council (1980). *The Nutrient Requirements of Ruminant Livestock.* Farnham Royal: Commonwealth Agricultural Bureaux.

Astatke, A., Reed, J.D. & Butterworth, M.H. (1986). The effect of diet restriction on work performance and weight loss of local Zebu and Friesian x Boran crossbred oxen. *ILCA Bulletin* 23. Addis Ababa, Ethiopia: International Livestock Centre for Africa.

Bakrie, B., Murray, R.M. & Hogan, J.P. (1988). The effect of work on intake and ruminal fluid, volatile fatty acid and NH_3 concentration of steers fed Rhodes grass hay. *Draught Animal Power Project Bulletin* 7, 9-13, James Cook University, Australia.

Bakrie, B., Murray, R.M., Hogan, J.P., Teleni, E. & Kartiarso (1989). Effect of load level on food utilisation by working cattle and buffalo. *Draught Animal Power Project Bulletin* 8, 23-26, James Cook University, Australia.

Bamualim, A. & Ffoulkes, D. (1988). Effect of work and level of feed intake on nutritional parameters and body weight change of swamp buffalo cows. *Draught Animal Power Project Bulletin* 7, 2-8, James Cook University, Australia.

Bamualim, A. & Kartiarso (1985). Nutrition of draught animals with special reference to Indonesia. In *Draught Animal Power for Production* (Ed. J.W. Copland), pp. 64-68. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series 10.

Barton, D. (1987). Draught power supply, nutrition and the work output of draught animals in Bangladesh. Report prepared for the Ford Foundation, Dhaka and FSRDP. Bangladesh Agricultural University, Mymensingh.

Bird, A.R., Chandler, K.D. & Bell, A.W. (1981). Effects of exercise and plane of nutrition on nutrient utilization by the hind limb of the sheep. *Australian Journal of Biological Science* 34, 541-550.

Blaxter, K.L., Clapperton, J.L. & Wainman, F.W. (1966). The extent of differences between six British breeds of sheep in their metabolism, feed intake and utilisation and resistance to climatic stress. *British Journal of Nutrition* 20, 283-294.

Brody, S. (1945). *Bioenergetics and Growth.* New York: Reinhold. (reprinted in 1964, Haffner, New York).

Brosh, A., Choshniak, I., Tadnor, A. & Shkolnik, A. (1986). Infrequent drinking, digestive efficiency and particle size of digesta in black Bedouin goats. *Journal of Agricultural Science, Cambridge* 106, 575-579.

Buranamanos, P. (1963). *A Survey of the Buffalo in Thailand.* Faculty of Veterinary Science, Kasetsart University, Bangkok, Thailand.

Chantalakhana, C. (1981). A scope on buffalo breeding for draught. In *Recent Advances in Buffalo Research and Development.* pp. 131-151. FFTC/ASPC, Taiwan.

Clar, U. (1991). Entwicklung einer Feldmethode zur Messung des Energieumsatzes bei Zugtieren. PhD thesis, Institut fur Tierproduktion in den Tropen und Subtropen der Universitat Hohenheim, Germany.

Codazza, D., Maffeo,G. & Redaelli, G. (1974). Serum enzyme changes and haemato-chemical levels in thoroughbreds after transport and exercise. *Journal of the South African Veterinary Association* 45, 331-334.

Dijkman, J.T. (1989). *The measurement of draught oxen in the field: the Oxylog for oxen.* MSc thesis, Centre for Tropical Veterinary Medicine, University of Edinburgh, Scotland.

Dijkman, J.T. (1992). A note on the influence of negative gradients on the energy expenditure of donkeys walking, carrying and pulling loads. *Animal Production* 54, 153-156.

English, P.B. (1966). A study of water and electrolyte metabolism in sheep. 1. External balance of water, sodium, potassium and chloride. *Research in Veterinary Science* 7, 233-257

FAO (1972). Manual on the Employment of Draught Animals in Agriculture. Rome, Italy: FAO.

FAO (1982). Report of the FAO Expert Consultation on Appropiate Use of Animal Energy In Agriculture in Africa and Asia. Rome, Italy: FAO.

Ffoulkes, D. (1986). Studies on working Buffalo - current research on nutritional aspects. Balai Penelitian Ternakliawi, Bogor.

Draught Animal News **6**, Centre for Tropical Veterinary Medicine, University of Edinburgh.

Ffoulkes, D. & Bamualim, A. (1989). Improving the nutrition level of draught animals using available feeds. In *Draught Animals in Rural Development* (Eds D. Hoffman, J. Nari and R.J. Petheram), pp. 118-113. International symposium on draught animals in rural development, Cipanas, Indonesia. ACIAR Proceedings Series 27.

Ffoulkes, D., Bamualim, A. & Panggabean, T. (1987). Utilisation of fibrous feeds by working buffaloes. In *The Utilisation of Fibrous Agricultural Residues as Animal Feeds* (Ed R.M. Dixon). Melbourne, University of Melbourne Printing Service.

Frisch, J.E. & Vercoe, J.E. (1969). Liveweight gain, food intake and eating rate in Brahman, Africander and Shorthorn x Hereford cattle. *Australian Journal of Agricultural Research* 20, 1189-1195.

Frisch, J.E. & Vercoe, J.E. (1977). Food intake, eating rate, weight gains, metabolic rate and efficiency of feed utilisation in *Bos taurus* and *Bos indicus* crossbred cattle. *Animal Production* 25, 343-358.

Gill, G.J. (1981). *Farm Power in Bangladesh.* Dev. Study 20. Vol I, University of Reading, Department Agricultural Economics and Management, Reading.

Goe, M.R. (1983). Current status of research on animal traction. *World Animal Review* 45, 2-17.

Goe, M.R. & McDowell, R.E. (1980). *Animal traction: guidelines to utilisation.* Cornell International Agriculture Mimeo. Ithaca, N.Y. Cornell University.

Graham, N. McC. (1985). Relevance of the British metabolisable energy system in the feeding of draught animals. In *Draught Animal Power for Production* (Ed. J.W. Copland) pp. 96-98. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series **10**.

Hall, W.C. & Brody, S. (1934). The energy cost of horizontal walking in cattle and horses of various ages and body weights. University of Missouri Agricultural Experiment Station. *Research Bulletin* 208.

Henning, P.H. (1987). The effect of increased energy demand through walking exercise on intake and ruminal characteristics of sheep fed a roughage diet. *Journal of Agricultural Science, Cambridge* **109**, 53-59.

Ibrahim, M.N.M. (1985). Nutritional status of draught animals in Sri Lanka. In *Draught Animal Power for Production* (Ed. J.W. Copland) pp. 84-89. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series 10.

International Livestock Centre for Africa (1990). Annual Report and Programme Highlights. Addis Ababa, Ethiopia: ILCA.

Kibet, P.K.F. & Hansen, R.M. (1985). Effect of walking while grazing on rumen digestion. *East African Agricultural and Forestry Journal* 51, 30-35.

King, J.M. (1983). *Livestock Water Needs in Pastoral Africa in relation to climate and forage. Research Report 7.* Addis Ababa, Ethiopia: International Livestock Centre for Africa.

Lawrence, P.R. (1985). A review of the nutrient requirements of draught oxen. In *Draught Animal Power for Production* (Ed. J.W. Copland) pp. 59-68. Townsville, Australia. ACIAR Proceedings Series 10.

Lawrence, P.R. (1987*a*). Nutrient requirements of working ruminants. In *An Introduction to Working Animals* (Ed Falvey, J.L.). MPW Australia, Melbourne, Australia.

Lawrence, P.R. (1987*b*). Mud, mud, glorious mud. *Draught Animal News* 7, 1-2. Centre for Tropical Veterinary Medicine, University of Edinburgh.

Lawrence, P.R. (1988). A review of the nutrient requirements of draught oxen. In *Draught Animal Power for Production* (Ed. J.W. Copland) pp. 59-63. An international workshop on draught power for production, Townsville, Australia, 10-16 July 1985. ACIAR Proceedings Series 10.

Lawrence, P.R. & Dijkman. J.T. (in press). The Oxylog for Oxen. Proceeding of the Fourth West African Animal Traction Network Workshop, Kano, Nigeria, 1990. Addis Ababa, Ethiopia: International Livestock Centre for Africa.

Lawrence, P.R. & Pearson, R.A. (1985). Factors affecting the measurement of draught force, work output and power of oxen. *Journal of Agricultural Science, Cambridge* 105, 703-714.

Lawrence, P.R., Sosa, R. & Campbell, I. (1989*a*). The underlying 'resting' energy consumption of oxen during work. *Proceedings of the Nutrition Society* 48, 154A.

Lawrence, P.R., Buck, S.F. & Campbell, I. (1989*b*). The metabolic rate of oxen after work. *Proceedings of the Nutrition Society* 48, 153A.

Lawrence, P.R. & Stibbards, R.J. (1990). The energy cost of walking, carrying and pulling loads on flat surfaces by Brahman cattle and Swamp Buffaloes. *Animal Production* 50, 29-39.

Leng, R.A. (1985). Muscle metabolism and nutrition in working ruminants. In *Draught Animal Power for Production* (Ed. J.W. Copland) pp. 69-77. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series 10.

Little, W., Sansom, B.F., Manston, R. & Allen, W.M. (1976). Effects of restricting the water intake of dairy cows upon their milk yield, body weight and blood composition. *Animal Production* 22, 329-339.

Louw, G.N. (1984). Water deprivation in herbivores under arid conditions. In *Herbivore Nutrition in the Subtropics and Tropics* (Eds F.M.C. Gilchrist and R.I. Mackie), pp. 106-128. Craighall, South Africa: The Science Press.

Ministry of Agriculture Food and Fisheries (1984). *Energy Allowances and Feeding Systems for Ruminants.* Reference Book 433. MAFF, London: HMSO.

Martin, D.G. & Teleni, E. (1989). Fatigue in buffaloes on different work loads. *Draught Animal Power Project Bulletin* 8, 2-6, James Cook University, Australia.

Mathers, J.C. (1984). Nutrition of draught animals. In *Animal energy in agriculture in Africa and Asia.* FAO Expert Consultation on Appropriate Use of Animal Energy in Agriculture in Africa and Asia, 15-19 Nov 1982. Animal Production and Health Paper 42, 60-66. Rome: Food and Agriculture Organisation.

Mathers, J.C., Pearson, R.A., Sneddon, J., Matthewman, R.W. & Smith, A.J. (1985). The use of draught cows in agricultural systems with particular reference to their nutritional needs. In *Milk Production in Developing Countries* (Ed. A.J. Smith), pp. 476-496. Edinburgh: Edinburgh University Press.

Matthewman, R.W., Dijkman, J.T. & Zerbini, E. (in press). Husbandry and management of male and female draught animals. 2nd Workshop of the West African Animal Traction Network, Kano, Nigeria 7-14 July 1990.

Matthewman, R.W., Merrit, J., Smith. A.J., Phillips, P. & Oldham, J.D. (1989). Effects of exercise on lactational performance in cattle. *Proceedings of the Nutrition Society* 48, 92A.

Munzinger, P. (1982). *Animal Traction in Africa.* GTZ, Eschborn, West Germany.

Pearson, R.A. (1986). Feeding and management of draught animals: A review. *Indian Journal of Animal Production and Management* 2, 48-69.

Pearson, R.A. (1988). *Research on draught animals in Nepal: Research on the nutrition and physiology of draught animals.* Report on EEC Research Project - EEC TSD A265-UK. Edinburgh. Centre for Tropical Veterinary Medicine, University of Edinburgh.

Pearson, R.A. (1990). A note on liveweight and intake and digestibility of food by draught cattle after supplementation of rice straw with the fodder tree *Ficus auriculata. Animal Production* 51, 635-638.

Pearson, R.A. & Archibald, R.F. (1989). Biochemical and haematological changes associated with short periods of work in draught oxen. *Animal Production* 48, 375-384.

Pearson, R.A., Lawrence, P.R. & Ghimire, C. (1989). Factors influencing the work done by draught oxen: A study in the Eastern hills of Nepal. *Animal* Production 49, 345-353.

Pethick, D. (1984). Energy metabolism of skeletal muscle. In *Ruminant Physiology - Concepts and Consequences.* Proceedings of a Symposium May 1984, pp. 227 - 287. Perth, University of Western Australia.

Preston, T.R. & Leng, R.A. (1987). *Matching Ruminant Production Systems with Available Resources in the Tropics and Sub-Tropics.* Armidale, Australia: Penambul Books.

Ribeiro, J.M. de C.R., Brockway, J.M. & Webster, A.J.F. (1977). A note on the energy cost of walking in cattle. *Animal Production* 25, 107-110.

Smith, A.J. (1981). Rqle of draught animals in agricultural systems in developing countries. In *Vegetable Productivity* (Ed. C.R.W. Spedding) pp. 247-262. MacMillan Publishers Ltd, London.

Starkey, P., Sirak Teklu & Goe, M.R. (1991). Animal Traction: An Annotated Bibliographic Database. Addis Ababa, Ethiopia: International Livestock Centre for Africa.

Teleni, E. & Hogan, J.P. (1989). Nutrition of draught animals. In *Draught Animals in Rural Development* (Eds D. Hoffman, J. Nari and R.J. Petheram) pp. 118-133. International symposium on draught animals in rural development, Cipanas, Indonesia. ACIAR Proceedings Series 27.

Teleni, E. & Pieterson, R. (1989). Unpublished work quoted in Teleni, E. and Hogan, J.P. (1989) Nutrition of draught animals. In *Draught Animals in Rural Development* (Eds D. Hoffman, J. Nari and R.J. Petheram) pp. 118-133. International symposium on draught animals in rural development, Cipanas, Indonesia. ACIAR Proceedings Series 27.

Thomas, C.K. & Pearson, R.A. (1986). Effect of head cooling on energy expenditure, feed intake and heat tolerance of Brahman and Brahman x Friesian cattle working on treadmills. *Animal Production* 43: 83-90.

Vercoe, J.E. (1970*a*). Fasting metabolism and heat increment of Brahman x British and British cattle. In *Energy Metabolism of Farm Animals* (Eds A. Schurch & C. Wenk), pp. 85-88. EAAP Publication No. 13, Juris, Zurich.

Vercoe, J.E. (1970*b*) The fasting metabolism of Brahman, Africander and Hereford x Shorthorn cattle. *British Journal of Nutrition* 24, 599-606.

Wanapat, M. (1985). Nutritional status of draught buffaloes and cattle in Northeast Thailand. In *Draught Animal Power for Production.* (Ed J.W. Copland) pp. 90-95. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series 10.

Wanapat, M., Varvikko, T. & Vanhatalo, A. (1990). The influence of selected chemical treatments on the ruminal degradation and subsequent intestinal digestion of cereal straw. *Australasian Journal of Animal Science* 3, 75-83.

Wachirapakorn, C. & Wanapat, M. (1989). The effect of nutrition on body condition prior to working in respect of draught capacity, voluntary feed intake, digestibility and physiological aspects of draught buffaloes. *Draught Animal News* 10, 9. Cent5re for Tropical Veterinary Medicine, University of Edinburgh.

Webster, C.C. & Wilson, P.N. (1980). *Agriculture in the Tropics.* Second Edition. London: Longmans.

Weston, R.H. (1985). Some considerations of voluntary feed consumption and digestion in relation to work. In *Draught Animal Power for Production* (Ed J.W. Copland) pp. 78-83. An international workshop on draught power for production, Townsville, Australia. ACIAR Proceedings Series 10.

Winugroho, M. (1988). The effect of work durations on voluntary feed intake and digestibility, liveweights and physiology of buffaloes fed a grass:rice straw diet. *Congress of the Sixth Federation of Asian Veterinary Associations* (FAVA), October 16-19, 1988, Depasar, Bali, Indonesia.

Winugroho, M. (1989). Mineral supplementation to working buffalo and cattle grazed on field grasses in Subang, West Java. *Draught Animal Power Project Bulletin* 9, 19. James Cook University, Townsville, Australia.

Zerbini, E., Gemeda, T., O'Neil, D. H., Howell, P. J. & Schroter, R. C. (1992). Relationship between cardio-respiratory parameters and draught work output in F1 crossbred dairy cows under field conditions. *Animal Production* 55, 1-10.

Table 1: Published values for energy expenditure for walking and working in draught ruminant animals and for the efficiency of doing work

Activity	Energy Expenditure (Average)	Animals	Authors
Walking	1.9	Cattle (*Bos taurus*)	Brody (1945)
(J/m per kg	2.0	Cattle (*Bos taurus*)	Ribeiro *et al.* (1977)
live weight)	0.5-2.8	Cattle (*Bos indicus*)	King (1983)
	2.0	Cattle	ARC (1980)
	2.1	Brahman Cattle/ Buffaloes	Lawrence & Stibbards (1990)
Carrying loads	2.6	Brahman Cattle	Lawrence &
(J/m per kg carried)	4.2	Water buffalo	Stibbards (1990)
Efficiency[1] of	0.30	Brahman Cattle	"
doing work pulling loads (work done/ energy used)	0.37	Buffaloes	"
Efficiency of doing work raising body weight (work	0.36	Brahman and Brahman x Friesian Cattle	Thomas & Pearson (1986)
done/energy used)	0.35	Cattle	ARC (1980)

[1] Efficiency is the ratio of output to input expressed as a fraction or a percentage.

TABLE 2: Estimated daily metabolisable energy (ME) requirements, dry matter intake (DMI) and ME intake (MJ) for draught ruminants at two levels of diet quality and at two levels of energy expenditure

		Working at:			
	W	1.2 mtce	1.6 mtce	DMI	MEI
	200	25.5	28.3	2.5	12.6
	250	30.0	33.3	3.0	14.9
	300	34.3	38.0	3.4	17.0
M/D=5	350	38.4	42.6	3.8	19.0
	400	42.3	46.9	4.2	21.0
	450	46.1	51.1	4.6	22.9
	500	49.8	55.2	4.9	24.7
	550	53.4	59.2	5.3	26.5
	600	56.9	63.1	5.6	28.2
	200	24.0	26.2	3.6	32.7
	250	28.2	30.8	4.3	38.5
	300	32.2	35.2	4.9	43.9
M/D=9	350	36.0	39.4	5.5	49.2
	400	39.7	43.5	6.0	54.2
	450	43.3	47.4	6.6	59.1
	500	46.6	51.2	7.1	63.8
	550	50.1	54.8	7.6	68.4
	600	53.4	58.4	8.1	72.9

mtce = maintenance DMI = Estimated DMI (kg)
ME = ME (MJ) requirements MEI = Estimated ME (MJ) intake
M/D = MJ ME/kgDM W = body weight

Formulae used (MAFF 1984):

DMI-g/kgW$^{0.73}$/day = 106.5q + 24.1
q = ME/GE
GE = 18.5 MJ/kgDM
ME for maintenance (MEm) = 0.36W$^{0.73}$
HI = (0.457-0.019M/D)MEm
ME = MEm + HI
HI = heat increment
HI for work assumed to be same as for maintenance

Anim. Prod. 1992, **54**: 153-156
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0003-3561/92/18170153$02.00

A note on the influence of negative gradients on the energy expenditure of donkeys walking, carrying and pulling loads

J. T. Dijkman

Centre for Tropical Veterinary Medicine, Easter Bush, Roslin, Midlothian EH25 9RG

The extra energy used for walking on the level and on negative gradients above that used when standing still (E_W) (J/m per kg live weight) was measured in two entire male donkeys (Equus asinus). *E_W was not affected by speed within the measured range (V = 0·6 to 1·3 m/s) but gradient (0, –10%, –15%) had a significant effect $E_{W\,level}$ = 0·97 (s.e. 0·02), $E_{W\,-10\%}$ = 0·55 (s.e. = 0·03) and $E_{W\,-15\%}$ = 0·67 (s.e. 0·03).*

The extra energy cost of carrying loads (E_C), defined as J/m per kg carried was measured using the same animals. Loads were placed over the animals shoulders and speed was varied within the range 0·6 to 1·3 m/s ($E_{C\,level}$ = 1·1 (s.e. 0·04), $E_{C\,-10\%}$ = 2·7 (s.e. 0·17) and $E_{C\,-15\%}$ = 3·3 (s.e. 0·20) were significantly different.

The energy cost of pulling loads (E_p) (J/m per kg) was measured while the animals pulled loads up to proportionately 0·17 of their live weight. The animals wore a breast-plate harness and walking speed was varied within the range 0·6 to 1·3 m/s. Mean values were 26·5 (s.e. 0·72) on the level, 15·3 (s.e. 1·2) on the –10% gradient and 6·2 (s.e. 0·43) on the –15% gradient.

The two donkeys used in this experiment were more efficient in both carrying and pulling loads than oxen and buffaloes. Negative gradients have a significant effect on energy consumption and when estimating the energy expenditure of working animals this factor should be taken into account.

Keywords: *donkeys, energy, work.*

Donkeys play an important rôle as work animals in the semi-arid and mountainous areas of Africa, Asia and Latin America. In addition to their traditional rôle as pack and riding animals, donkeys are often used for light cultivation tasks, threshing, drawing water and carting. Despite this, donkeys have a low status in many of the countries where they are now found. Compared with cattle and buffaloes, the most numerous draught animals in the tropics, little information is available in the literature on their requirements for work or their working efficiency. In ruminants the unit energy costs of the various activities of working, walking, carrying loads, pulling loads (Lawrence and Stibbards, 1990) and raising the animal's own weight when walking uphill (Thomas and Pearson, 1986), have been measured, but no similar information is available for donkeys. The objective of this study was to investigate the energy costs of walking, carrying loads and pulling loads by donkeys. The resulting information should enable the energy requirements of working donkeys to be estimated in the field from measurements of the type and amount of work done.

Two 2-year-old donkeys (*Equus asinus*) weighing 115 and 110 kg respectively, at the start and 148 and 142 kg, respectively, at the end of the experiment, were used. The study was carried out at the Centre for Tropical Veterinary Medicine from February to July 1990. The donkeys were housed together in an open sided shed and bedded on straw. Diurnal maximum and minimum ambient temperatures varied between 10 and 23°C during the experiments. Hay was provided *ad libitum* (8·5 MJ metabolizable energy (ME) per kg dry matter) and 1 kg concentrate (14 MJ ME per kg dry matter), was provided in two equal portions at 08.00 and 15.00 h on non-working days with an additional 0·23 to 0·5 kg given after work on working days.

Both donkeys were trained, during a 3-week period, to walk on a treadmill at speeds from 0·6 to 1·3 m/s and to carry and pull loads. During the carrying experiments the animals wore a padded saddle made from Dexion® slotted angle iron over their shoulders on which weights of up to 20 kg were carried. During the pulling experiment the donkeys wore a breastplate harness. Loads (5 to 18 kg) were provided by weights suspended in a metal frame behind the treadmill and connected to the animal's harness via a chain and a system of pulleys (Lawrence and Stibbards, 1990).

An adjustable sloping wooden ramp was constructed and placed under the treadmill frame to provide the required downhill gradient. Determinations for each activity were made on slopes of 0, -10% and -15%. Speeds during each activity were varied in the range 0·6 to 1·3 m/s. The donkeys were tethered while on the treadmill. However they both walked readily and maintained slack lead ropes at all times so this would not have affected measurements.

The oxygen consumption and carbon dioxide production of the animals were determined using the open-circuit calorimetry system described by Richards and Lawrence (1984). The continuous traces of O_2 consumption and CO_2 production and air-flow rate were amplified and stored in a modifed personal computer. Values were averaged at suitable intervals and stored for subsequent interpretation. Statistical analysis was carried out using analysis of variance.

The animals were allowed to reach a steady state of energy consumption which usually took 5 to 10 min, whereupon measurements continued for a further 15 min. In this way it was possible to obtain the energy consumption associated with the particular activity. The distance travelled was calculated from the number of revolutions of the treadmill belt multiplied by its length.

The energy costs of the different activities were defined in the manner described by Lawrence and Stibbards (1990): the energy cost of walking E_W (J/m walked per kg live weight) = [energy used while walking – energy used while standing still]/[distance walked (m) × live weight (kg)]. The extra energy used for carrying loads while walking, E_C (J/m walked per kg carried) = [energy used while walking with a load – energy used when walking unloaded at the same speed]/[distance walked (m) × load carried (kg)]. The energy cost of pulling loads (E_P) (J/m walked per kg pulled) = [energy expended when pulling a load energy – energy expended to walk the same distance but unloaded at the same speed]/[distance walked (m) × load pulled (kg)].

During measurement of the energy cost of the different activities the following routine was used: E_W — standing, walking, standing; E_C — walking unloaded, carrying 10, 14, 20 kg, walking unloaded (V = constant); E_P — walking unloaded, pulling a load, walking unloaded (V = constant). Animals pulled up to 18 kg on downhill slopes, but only up to 14 kg on the level. For the energy cost of standing and walking unloaded the average of the first and final values were taken.

The energy costs of walking are given in Table 1. There was no significant difference between the

Table 1 *The energy cost of walking by two donkeys as influenc[ed by] downhill gradient*

Slope	No of observations	Average energy for walking (E_W) (J/m per kg)	s.e
0	28	0·97 ***	0·02
10%	35	0·55 **	0·03
−15%	31	0·67	0·03

results obtained from each animal. E_{Wlevel} [w]as significantly greater than $E_{W-10\%}$ and E_{W}[$_{-15\%}$] ($P < 0·001$) and $E_{W-15\%}$ was significantly greater t[han] $E_{W-10\%}$ ($P < 0·01$). The animals showed no signific[ant] correlation between E_W and the range of walk[ing] speeds used on any of the slopes ($r = -0·19$).

The energy costs of carrying loads are given in T[able] 2. There was no significant difference between [the] results obtained from each animal. E_C increased w[ith] the steepness of the downhill slope (Table [2]). Differences between E_{Clevel} and $E_{C-10\%}$ and E_{C}[$_{-15\%}$] were significant ($P < 0·001$). $E_{C-15\%}$ was significan[tly] greater than $E_{C-10\%}$ ($P < 0·01$). The range of walk[ing] speeds and size of the tested loads had no signific[ant] influence on the energy cost of carrying loads on [any] of the slopes.

Whilst there was only a small proportional differe[nce] between E_{Clevel} and E_{Wlevel} per kg carried (0·13 J [/m] per kg carried: 0·134 higher than per kg body wei[ght] carried), analysis of the data showed that E_{Clevel} [w]as significantly greater than E_{Wlevel} per m per kg carr[ied] ($P < 0·001$).

As expected the E_P decreased with the steepnes[s of] the downhll slopes (Table 3). Speed of walking [...]

Table 2 *The energy cost of carrying loads by two donkey[s as] influenced by downhill gradient*

Slope	No. of observations	Range of weights (kg)	Average energy for carrying (E_C) (J/m per kg)	s.[e]
0	32	10 to 20	1·1 ***	0·[illegible]
−10%	31	10 to 20	2·7 **	0·1
−15%	31	10 to 20	3·3	0·2

Table 3 *Energy cost of pulling loads by two donkeys on different downhill slopes*

Slope	No. of observations	Load (kg)	Average energy for pulling (E_P) (J/m per kg)	s.e.
0	27	5 to 14	26·5	0·72
			***	
-10%	26	5 to 18	15·3	1·2
			***	
-15%	27	5 to 18	6·2	0·43

no significant effect on E_P in the range of speeds tested. Analysis of variance showed no significant differences within or between the data obtained from both animals ($P > 0·05$). Whilst the animals on the downhill slopes willingly pulled proportionately up to 0·17 of their body weight, they were only willing to pull up to 0·09 of their body weight on the level for long enough to get a reliable measurement. E_{Plevel} was significantly higher than on the −10% and −15% slopes ($P < 0·001$). $E_{P-10\%}$ was significantly higher than on the $E_{P-15\%}$ ($P < 0·001$).

The values obtained in this study for E_{Wlevel}, and E_W on the downhill slopes are similar to results reported by Yousef and Dill (1969) and Yousef, Dill and Freeland (1972). Since in these experiments only O_2 consumption (V_{O_2}) was measured, E_W was calculated using $E_W = 20·46 \times V_{O_2}$ (McLean, 1972) to enable comparison.

E_{Wlevel} in donkeys seems to be very much smaller than values reported for cattle (Brody, 1945; Agricultural Research Council (ARC), 1980; Lawrence and Stibbards, 1990), buffaloes (Lawrence and Stibbards, 1990) and horses (Brody, 1945; Hintz, Roberts, Sabin and Schryver, 1971), but comparable with values obtained for camels (Yousef, Webster and Yousef, 1989). The formulae proposed by Tucker (1969) and Taylor, Heglund and Maloiy (1982) for predicting the energy cost of E_W both highly overestimate the actual value obtained in this study for donkeys.

The superior economy of the donkey for E_{Wlevel} has been explained in several ways, ranging from the lack of ankle flexion (Yousef *et al.*, 1972) to the presence of elastic ligaments in the foot (Hildebrand, 1960). All these aspects may play a rôle in the adaptation of the donkey to harsh environments and might further explain the similarity between the values obtained in this experiment and those reported for camels.

Whilst $E_{W-10\%}$ and $E_{W-15\%}$ were significantly lower than E_{Wlevel}, the results show that as the steepness of the gradient increases, the advantage of conferring the potential energy of the body into kinetic energy is reduced. This effect is caused by the fact that the animal starts 'braking' to control its movement.

Lawrence and Stibbards (1990) report a significant positive correlation between E_{Wlevel} and walking speed for cattle and buffaloes. In this experiment no such correlation was found. It is therefore suggested that the 'comfortable' range of walking speeds is greater for donkeys.

There are few reports about the extra energy expended by donkeys while carrying loads. Observation for E_{Clevel} by Yousef and Dill (1969) and Yousef *et al.* (1972) are similar to those reported in this study. Energy consumption while carrying loads did not change significantly on downhill slopes as compared with E_W in these studies. Energy expenditure while carrying loads was however, calculated using total weight (body weight + load) which tends to underestimate the actual energy cost of the extra weight carried. Our donkeys while carrying loads downhill had difficulty in controlling their movement. Another problem encountered during the trials was the shifting of both saddles and weights on the downhill slopes. In the previously mentioned experiments, human beings provided the extra weight and would be able to adjust their position to the prevailing slope. This would suggest that when animals have to walk a long downhill route, the placement of the load should be adjusted such that the vector of the weight is a diagonal through the knee joint.

E_{Clevel} in donkeys was very much lower than the values reported for cattle (ARC, 1980; Lawrence and Stibbards, 1990), buffaloes and ponies (Lawrence and Stibbards, 1990), but, as with E_W, similar to camels (Yousef *et al.*, 1989). Taylor (1986), suggested that anatomic adaptation allows African women to support small loads using non-muscular structural elements. The donkey may have a similar adaptation. Taylor (1986), also suggested that more economic muscle fibre is used for power generation. Donkeys are poorly fed in most tropical countries which might well have resulted in the selection of animals using the least energy for work, thereby enabling survival under adverse management conditions.

E_{Plevel} is similar to efficiencies obtained for buffalo but higher than values reported for Brahman cattle (Lawrence and Stibbards, 1990). The steepness of the downhill slope has a significant effect on E_P. The experimental procedure enabled the animals to 'hang' in their harnesses, thereby fully utilizing the potential energy of their body weight and probably reducing the energy cost of locomotion. It has to be born in mind however, that while simulating a 'ploughing' situation, this procedure does not simulate a donkey pulling a wheeled cart. The forces playing while pulling a cart downhill however are very similar to the carrying of loads.

Although donkeys are often referred to as being 'pack animals', their efficiency of pulling loads has been shown to be very high. The disadvantage of their relatively small body weight for pulling compared with cattle is partly offset by their higher working speed which could be gainfully employed during weeding operations.

Acknowledgements

I wish to thank Mr Iain Campbell and Mr Paul Wright for their technical assistance. Dr Derek Anderson is thanked for the loan of his donkeys.

References

Agricultural Research Council. 1980. *The nutrient requirements of ruminant livestock.* Commonwealth Agricultural Bureaux, Slough.

Brody, S. 1945. *Bioenergetics and growth. With special reference to the efficiency complex in domestic animals.* Reinhold, New York.

Hildebrand, M. 1960. How animals run. *Scientific American* 202: 148-156.

Hintz, H. F., Roberts, S. J., Sabin, S. W. and Schryver, H. F. 1971. Energy requirements of light horses for various activities. *Journal of Animal Science* 32: 100-102.

Lawrence, P. R. and Stibbards, R. J. 1990. The energy of walking, carrying and pulling loads on flat surfaces Brahman cattle and swamp buffalo. *Animal Production* 29-39.

McLean, J. A. 1972. On the calculation of heat produc from open-circuit calorimetric measurements. *British Jou of Nutrition* 27: 597-600.

Richards, J. I. and Lawrence, P. R. 1984. The estimatio energy expenditure from heart rate measurements working oxen and buffalo. *Journal of Agricultural Scie Cambridge* 102: 711-717.

Taylor, C. R. 1986. Carrying loads: the cost of genera muscular force. *New Physiological Science* 1: 153-155.

Taylor, C. R., Heglund, N. C. and Maloiy, G. M. O. 19 Energetics and mechanics of terrestrial locomotion. *Jou of Experimental Biology* 97: 1-21.

Thomas, C. K. and Pearson, R. A. 1986. Effects of amb temperature and head cooling on energy expenditure, fo intake and heat tolerance of Brahman and Brahman Friesian cattle working on treadmills. *Animal Production* 83-90.

Tucker, V. A. 1969. Energetic cost of locomotion in anim *Comparative Biochemistry and Physiology* 34: 841-846.

Yousef, M. K. and Dill, D. B. 1969. Energy expenditure desert walks: man and burro, *Equus asinus*. *Journal of App Physiology* 27: 681-683.

Yousef, M. K., Dill, D. B. and Freeland, D. V. 19 Energetic cost of grade walking in man and burro, *Eq asinus*: desert and mountain. *Journal of Applied Physiology* 337-340.

Yousef, M. K., Webster, M. E. D. and Yousef, O. M. 19 Energy cost of walking in camels, *Camelus dromedar* *Physiological Zoology* 62: 1080-1088.

(*Received* 4 *March* 1991—*Accepted* 29 *July* 1991)

Reprint from

ISOTOPE AND RELATED TECHNIQUES IN ANIMAL PRODUCTION AND HEALTH

PROCEEDINGS OF AN INTERNATIONAL SYMPOSIUM
ON NUCLEAR AND RELATED TECHNIQUES
IN ANIMAL PRODUCTION AND HEALTH
JOINTLY ORGANIZED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY
AND THE
FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS
AND HELD IN VIENNA, 15-19 APRIL 1991

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 1991

TECHNIQUES FOR MEASURING WHOLE BODY ENERGY EXPENDITURE OF WORKING ANIMALS: A CRITICAL REVIEW

P.R. LAWRENCE
International Livestock Centre for Africa,
Kaduna

R.A. PEARSON, J.T. DIJKMAN
Centre for Tropical Veterinary Medicine,
University of Edinburgh,
Easter Bush, Roslin, Midlothian,
United Kingdom

Abstract

TECHNIQUES FOR MEASURING WHOLE BODY ENERGY EXPENDITURE OF WORKING ANIMALS: A CRITICAL REVIEW.

All feasible methods for determining the whole body metabolism of draught animals are indirect and most involve measuring gaseous exchange. The relationship between gaseous exchange and energy metabolism is discussed and the open circuit system described. However, in its classic form it can be applied to draught animals only when they are resting in a respiration chamber or at work on a treadmill or circular race. Three portable devices for measuring the oxygen consumption of animals working in fields are described. All involve the use of an airtight face mask so that total respiratory volume can be measured and samples of inspired and expired air taken for analysis. Although all three devices work well in a technical sense, users often experience difficulty in getting experimental animals to behave normally when wearing the face masks and the measuring systems can become inaccurate if the animals start to pant. The theory and applicability of two tracer methods are discussed. Labelled carbon methods appear not to be very accurate and involve continuous infusion of label. They may be useful for determinations lasting a few hours. The double and triple labelled water methods may find application for measurements over one or two weeks now that several of the objections to the use of these methods on large ruminants have been met. However, both types of tracer method measure only CO_2 output, from which energy consumption has to be inferred, and the latter method is very expensive. Two other methods involve counting the number of heart beats and measuring the type and amount of physical activity of the animal. Both methods rely heavily on data from laboratory studies to link these parameters to energy expenditure. The validity of these methods and the techniques for collecting the relevant data from the animals are briefly discussed.

1. INTRODUCTION

Measurement of the heat production and/or energy consumption of animals, including human beings, has been a preoccupation of physiologists for over two hundred years [1]. Most of the early attempts were made simply to determine the source of animal heat [2, 3], but once it became firmly established that all heat produced by animals comes ultimately from the oxidation of food then such measurements were directed increasingly towards finding the energy costs to the animal of performing various functions. These functions fall into two broad categories, those associated with various aspects of digestion, metabolism and efficiency of utilization of food [4] and those associated with movement and the performance of work. The former group is generally easier to study because the experimental subject usually stays in one place. The latter by definition involves taking complex measurements while the animal is in motion.

In recent years there has been a resurgence of interest in the energy metabolism of working animals as it has become apparent that they will continue to provide much of the power used on farms in developing countries for the foreseeable future. However, the food energy requirements of such animals are large and land for grazing becomes scarcer as the human population grows [5]. A knowledge of the energy expenditure of such animals under as wide a range of conditions as possible is of great use in devising more efficient ways of employing them and of making the best uses of the food resources available.

2. DIRECT MEASUREMENT OF HEAT OUTPUT

Many methods have been devised to measure directly the heat produced by animals [6]. However, it seems unlikely that any of them would ever prove feasible or useful as a means of measuring the whole body energy metabolism of working animals.

3. INDIRECT MEASUREMENT OF WHOLE BODY ENERGY METABOLISM

All methods which have been applied to draught animals fall into the category of indirect measurement. As the term 'indirect' implies, the energy metabolism is calculated from other quantities which can be more easily measured rather than being measured directly. Chief amongst these is the gaseous exchange of the animal, that is its oxygen consumption and its production of carbon dioxide and, in the case of ruminants, methane. The relative proportions of the components of the gaseous exchange can be used to infer the proportions of the major nutrients being oxidized by the animal and the actual amounts used to calculate the quantities of these nutrients.

3.1. The quantitative relationship between energy metabolism and gaseous exchange

The following formula for predicting energy metabolism from gaseous exchange may be derived using data drawn up by Brouwer [7], and it appears in theory to be applicable to adult draught animals [8]:

$$H = 16.2C + 5.1P - 6.5U - 2.0M \quad (1)$$

where

H is the heat produced (kJ);
C is the O_2 consumption (std L);
P is the CO_2 production (std L);
U is urinary nitrogen (g);
M is the CH_4 production (std L).

Application of this formula to the 24 h metabolism of a 725 kg ox fed a low protein diet is shown in Table I, from which it can be seen that the last two factors, the methane and urinary nitrogen, have quantitatively little influence on the calculated energy consumption (0.7 and 0.5% respectively) and in most cases can be omitted.

Many of the methods used to measure energy metabolism of working animals in the field measure O_2 consumption only. In this case, energy consumption may still be calculated if assumptions are made regarding the ratio of CO_2 produced to O_2 consumed, also known as the respiratory quotient or RQ:

$$\mathrm{RQ} = \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}}$$

Although the RQ can theoretically vary from 0.7 (oxidation of fat only, e.g. in starvation) to 1.3 (maximum production of fat from carbohydrate) the 24 h average RQ for adult ruminants fed around maintenance level is generally in the range of 0.8–1.0. In the case of draught animals, however, larger variations can occur during work, as shown in Fig. 1. In this case the RQ changed from about 1.0 after the animal's morning meal to 0.7 after 6 h work. Since O_2 accounts for about 77% of the calculated energy expenditure, assuming an RQ of 1.0 would cause an error of 7.2% by the end of the day.

TABLE I. CALCULATION OF 24 h ENERGY CONSUMPTION OF A 725 kg OX FED AT MAINTENANCE ON A HIGH CARBOHYDRATE, LOW PROTEIN DIET

O_2 consumption	3053 L
CO_2 production	3002 L
CH_4 production	213 L
Urinary nitrogen (estimate)	50 g

Energy consumption

$$= (3053 \times 16.16) + (3002 \times 5.09) - (50 \times 6.5) - (213 \times 2.0) \text{ kJ}$$
$$= 49\,336 + 15\,280 - 325 - 426 = 63\,865 \text{ kJ}$$

Relative importance of the various factors

O_2	77.3%
CO_2	23.9%
CH_4	0.7%
Urinary N	0.5%

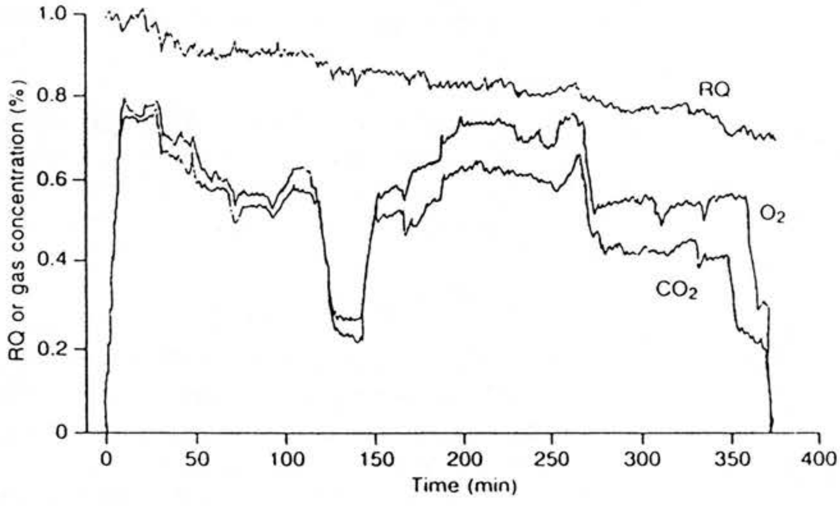

FIG. 1. Oxygen consumption and CO_2 production (as a percentage of total air flow) and RQ of a 450 kg ox during a day's work.

Before using apparatus which measures O_2 only, therefore, it is advisable to take some short term measurements of CO_2 as well to find the range of RQ values likely to be encountered. This argument is even more important in techniques which measure CO_2 only. The CO_2 factor in Eq. (1) is only 24% of the total and changes of only 0.1 in RQ will produce an error of 10% in the calculated energy expenditure.

4. METHODS FOR MEASURING GASEOUS EXCHANGE IN DRAUGHT ANIMALS

4.1. The classic 'open circuit' system

The 'open circuit' method was one of the first to be devised [9] but could originally be applied only to animals in chambers as the equipment available for measuring gas concentrations required discrete samples of gas for analysis and each analysis took many minutes. It was therefore impossible to follow the rapid fluctuations in the rate of gaseous exchange characteristic of draught animals. The best that could be achieved was to take a continuous sample over an extended period to obtain an average value.

With the advent of modern methods of gas analysis with response times of fractions of a second it became possible to take measurements from working animals wearing 'leaky' face masks. The principle of the method, however, is the same as for animals in chambers. Air is passed over the animal at a constant rate and changes in gas concentrations between the ingoing and outgoing air are monitored. In any given period the gaseous exchange is therefore the product of the flow rate and the average concentration difference.

An example of this kind of apparatus which can be used for large draught animals is the one built by Lawrence at the Centre for Tropical Veterinary Medicine (CTVM) in Edinburgh [10] (Fig. 2). Here the constant airflow is provided by a multistage centrifugal pump driven by an induction motor. The air is drawn through a face mask worn by the animal when it is working, or through a respiration chamber when resting. The flow rate for a particular experiment is chosen so that the CO_2 concentration in the mixed expired air does not exceed 1% and therefore will not stimulate the animal's respiration if rebreathed [11]. After drying, a sample of the mixed expired air is passed through one channel of a differential paramagnetic O_2 analyser while dried fresh air is passed through the other. Further samples are passed continuously through CO_2 and CH_4 infrared analysers. The amplified outputs from all these meters are sampled at 5 Hz by a modified personal computer. Values are averaged at suitable intervals and stored for subsequent calculations of gaseous exchange.

The advantages of such systems are that they are reliable and accurate and can be used for measurements over any length of time from a few minutes to days if a

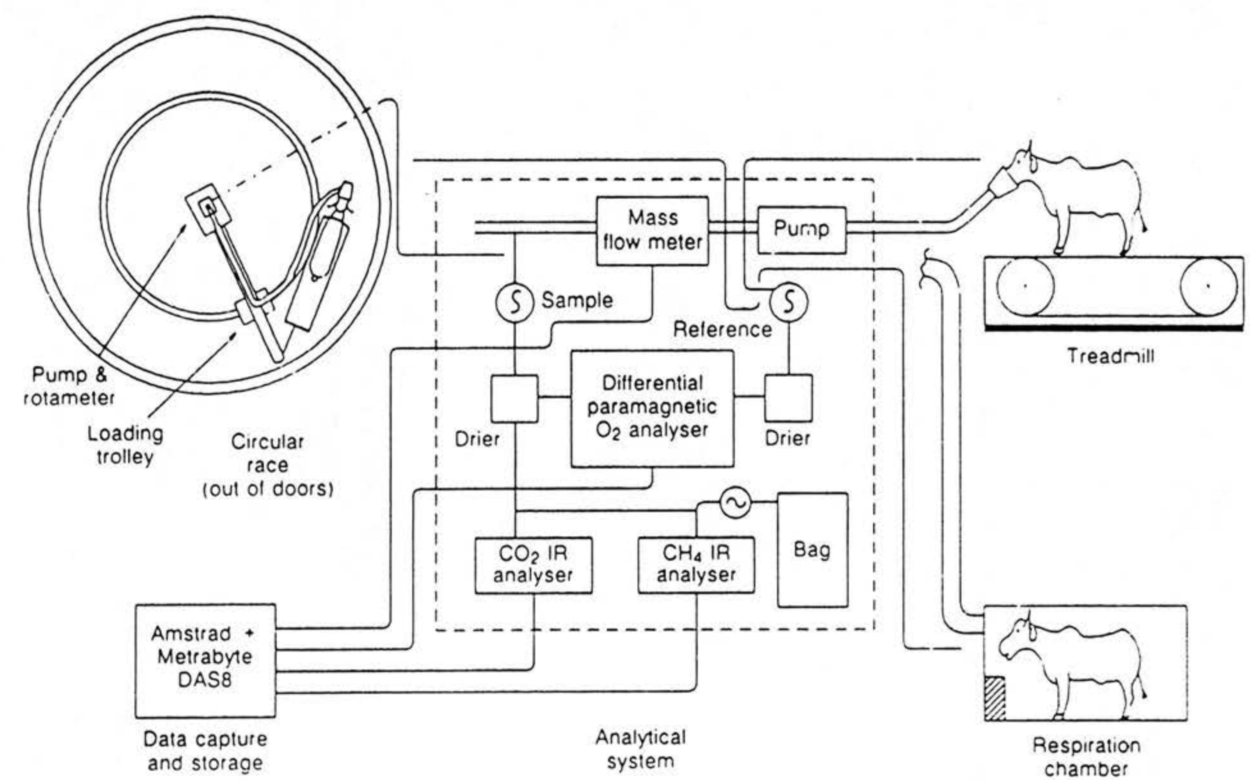

FIG. 2. Classic 'open circuit' gas analysis system at the CTVM, Edinburgh, for use with large draught animals at rest or during work.

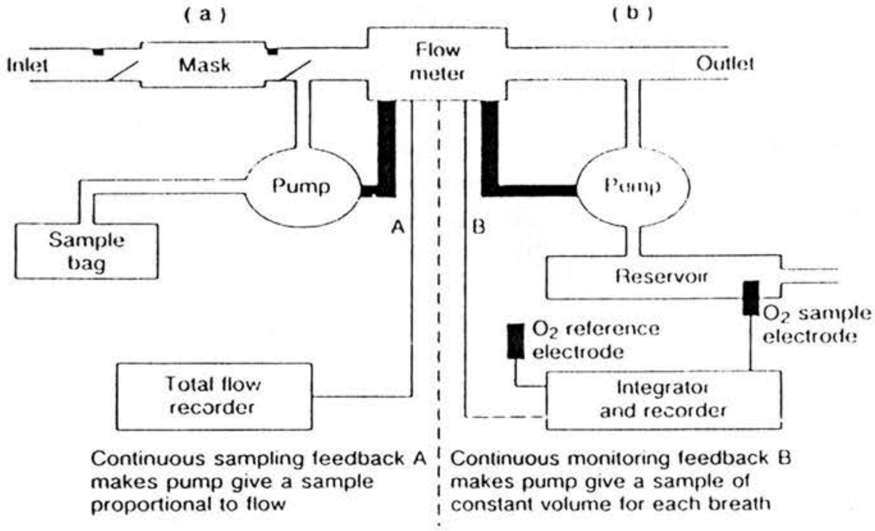

FIG. 3. The basic layout of two methods of portable 'breath by breath' analysis.

respiration chamber is also available. The main disadvantage is that the apparatus is not portable. This means that when used for working animals, some arrangement such as a treadmill or circular race must be made so that the animal can stay more or less in one place. This also precludes the animal's doing any normal agricultural work such as ploughing, and although various aspects of the natural environment such as soil condition and gradients may be simulated by using the circular race and the treadmill respectively, the technique must remain essentially a 'laboratory' one.

4.2. Portable 'breath by breath' analysers

At present, 'breath by breath' apparatus appears to be the one most favoured for use with draught animals in the field. No fewer than three systems have been developed in recent years.

In contrast to the classic open circuit system, in which air is pumped through a leaky face mask at a constant rate, in these devices the experimental animal wears an airtight face mask fitted with inlet and outlet valves and a flow meter which measures the volume of each breath (Fig. 3). In some instruments a sample of expired air is taken which is a constant proportion of each breath (Fig. 3(a)). The gas concentrations of this cumulative sample are thus the averages of the gas expired in a given time. Total gaseous exchange is calculated from the change in gas concentrations between the inspired air and the sample multiplied by the total flow. Energy expenditure can be calculated after suitable corrections to the gas volumes have been made for temperature, pressure and humidity. The principle of this kind of apparatus was first applied to humans [12] and has also been used for oxen by Clar at Hohenheim, Germany [13], as a preliminary to developing an apparatus of the type illustrated in Fig. 3(b).

In this type of apparatus each breath is analysed on the spot. This overcomes the major disadvantages of the proportional sampling devices, which are that (1) changes in metabolic rate during an experiment cannot be followed unless many samples are taken for analysis, and (2) the apparatus cannot be used very far away from a laboratory because it is difficult to preserve gas samples for more than a day or so without their composition changing.

However, the true breath by breath analysers also have intrinsic problems. For example, the response of the O_2 sensors and the flow meters must be very rapid even when a temporary reservoir of the sort shown in Fig. 3(b) is used. This usually limits the analysis to one component, with O_2 being the one of choice.

Hornicke et al. [14] built an apparatus for use with horses. Airflow was detected using a strain gauge pneumotachograph and O_2 concentrations were monitored by a fast polarographic O_2 electrode. Signals from both sensors were transmitted by radio back to the laboratory for analysis by computer. Such a flow meter is good for this kind of application because it offers virtually no obstruction to the

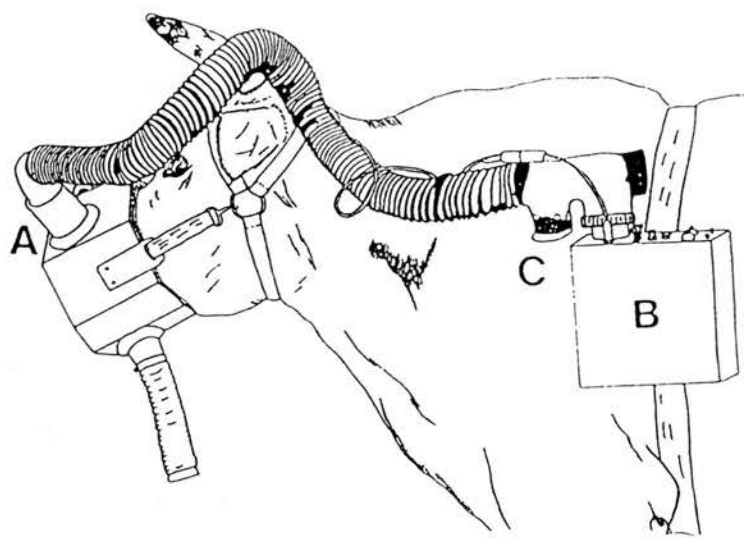

FIG. 4. The Oxylog fitted to a cow: A, inlet valve and turbine flow meter; B, Oxylog signal processing unit; C, sample bypass.

passage of air. However, because there are no valves and the horse breathes both in and out through the flow meter there is no way to average the concentration of gases in the expired air even over a few breaths and thus the speed of response of the O_2 sensors becomes of paramount importance. Also, the flow meter tends to become contaminated by dust and moisture, which causes its response to become non-linear.

Because of the above problems this apparatus achieved only a moderate success. It remains, however, probably the only feasible approach for an animal whose metabolic rate can change as rapidly and to such an extent as that of a horse. Changes in the metabolic rate of working oxen are less dramatic (up to about 5 times maintenance level as opposed to 15 times for horses) and so the technical problems of breath by breath analysis for these animals are less acute.

The apparatus of Clar [13] mentioned earlier uses a mask made from transparent PVC on a model of a cow's head. It has one inlet valve (45 mm) on either side of the mask and a larger outlet valve (60 mm) in the middle. A PVC cap at the bottom of the mask can be opened to let out saliva and condensed water. The mask is strapped to the animal's head using a close fitting adapter. Between 2 and 3.5% of the total expired air is drawn from a gas meter by a pump and stored in an aliquot collection bag. Subsequent CO_2 and O_2 concentrations in the samples are obtained by measuring their partial pressures with a blood gas analysis system.

Two other devices for measuring the O_2 consumption of working oxen have recently been developed.

Schroeter at the Imperial College of Science and Technology, London, working in conjunction with AFRC Engineering, Silsoe, Bedfordshire, United Kingdom, has developed a system in which flow rate is measured using a heated pneumotachograph [15]. This avoids problems caused by the condensation of water vapour from the animal's breath. Samples of expired air are passed over polarographic O_2 electrodes in a small reservoir which at any time contains samples from several previous breaths. The size of the reservoir was chosen so that the O_2 concentration changed sufficiently slowly for the electrodes (response: 90% in 300 ms) to follow it accurately. Signal processing and collection of data are done by a microprocessor based data logger which forms part of the portable apparatus. Total airflow and O_2 consumption are calculated by computer after the data have been off-loaded. The apparatus is currently in regular use at the Holetta Research Station, Ethiopia, of the International Livestock Centre for Africa (ILCA), where it is being used to study the energy metabolism of working cows; it has also been used with camels in Morocco.

Lawrence and Dijkman, working at the CTVM in Edinburgh, approached the problem by adapting an apparatus, the Oxylog (P.K. Morgan Ltd, Kent, United Kingdom), which had originally been designed for use with human beings [16] and which has proved reliable in long term field trials and accurate compared with laboratory methods [17]. The Oxylog uses a turbine flow meter mounted on the inlet side of the face mask (Fig. 4).

There are two advantages to having the flow meter in this position. Firstly, it avoids the problem of condensation of water vapour from the animal's breath, and secondly, if the inlet volume is used to calculate O_2 consumption and hence energy production, this partially compensates for any inaccuracies caused by changes in RQ. The reason for this is that at low RQ values more O_2 is consumed than CO_2 is produced. This means that the volume of the exhaled air is less than the inhaled air. Using the volume of inhaled air in calculations will therefore overestimate O_2 consumption at low RQs. On the other hand the use of a constant factor to calculate energy consumption from O_2 consumption leads to an underestimation of energy at low RQs. Using values for the total inflow of air will therefore give more accurate values for energy consumption [18].

After each breath a small reciprocating pump takes samples of the air entering and leaving the mask. The samples are passed into separate reservoirs containing a solid desiccant which give 'running average' O_2 concentrations which are measured using two polarographic O_2 electrodes linked differentially. The electronic system calculates and displays total O_2 consumption and total volume of inspired air at STP after making corrections for atmospheric temperature, pressure and humidity. Other functions allow the display of O_2 partial pressure difference between the inlet and outlet, and minute volumes of O_2 consumption and airflow. All outputs can be linked to a data logger and recorded automatically (Fig. 5).

Several adaptations were necessary in order to use the Oxylog for oxen [19, 20]. Firstly, a mask was made to fit oxen which incorporated a saliva trap and allowed the ox to be guided either by a halter or by a nose ring. Initial attempts to seal the mask to the animal's face using foam rubber inside the mask proved unsatisfactory. The present seal consists of an annular cuff of 1 mm thick natural rubber which seals perfectly at a point just behind the animal's nose when the mask is pushed onto the face (Fig. 4). The basic frame of the mask is made from 10 mm plywood and is of a geometrically simple shape. This means that new masks to fit animals of different sizes can be made quickly, easily and cheaply.

Secondly, larger versions of the turbine flow meter were made. It was found possible to make scaled-up versions of this type of flow meter which gave good linear responses when calibrated using a reciprocating pump operated at different speeds to give a range of flow rates.

The capacity of the inlet and outlet valves was increased simply by increasing their number from one to three and nesting them in a larger tube. Finally, the tube connecting the mask to the Oxylog was fitted with a bypass so that only a fraction of the air passed the sampling point.

The ability of the modified system to measure O_2 consumption accurately was checked first of all by passing a known volume of air through the flow meter with the reciprocating pump whilst surrounding the O_2 electrodes with a standard gas of known composition. The results of one such test at different flow rates are shown in Fig. 6. Secondly, the whole system was checked against the standard open circuit

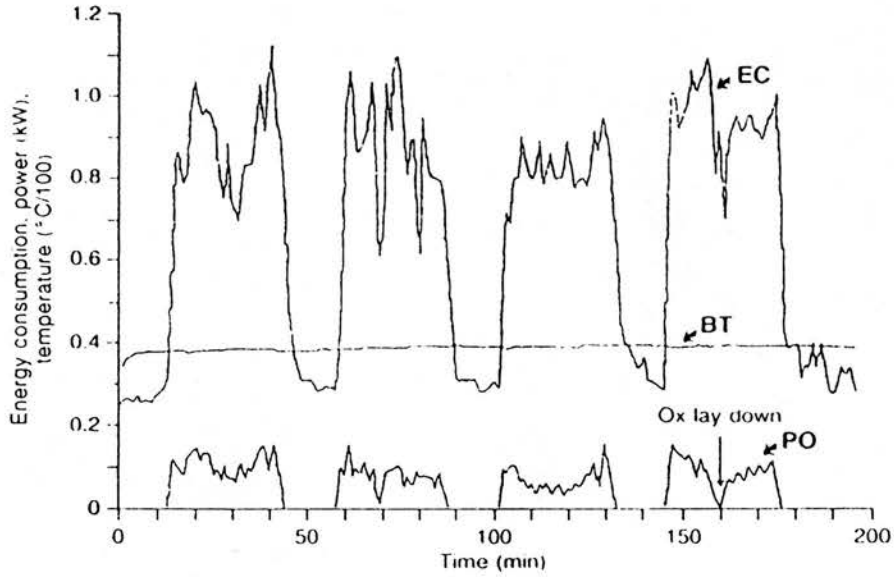

FIG. 5. Energy consumption calculated from O_2 consumption (EC), body temperature (BT) and mechanical power output (PO) over 3 h of an ox ploughing in Nepal. The O_2 consumption was continuously monitored using an Oxylog and all parameters were continuously recorded using a data logger.

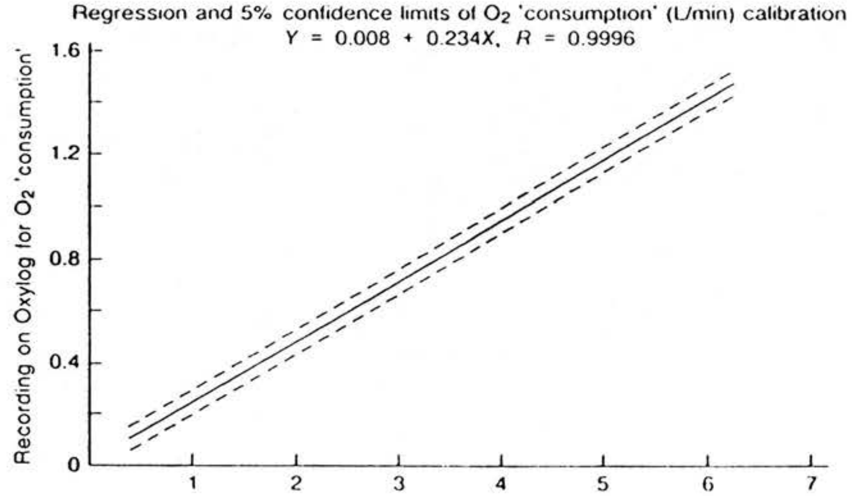

FIG. 6. Results of a calibration test in which the O_2 electrodes of the Oxylog were surrounded by a standard gas and various ventilation rates were provided by a reciprocating pump.

TABLE II. COMPARISON OF MEASUREMENTS (LASTING AT LEAST 30 min) OF O_2 CONSUMPTION (L) ON THE OPEN CIRCUIT SYSTEM AND THE OXYLOG

Open circuit	Oxylog	% difference
293.2	305.7	−4.3
285.5	276.3	3.2
263.3	250.1	5.0
244.9	231.2	5.6
223.5	217.9	2.5
198.0	192.0	3.0
197.3	189.1	4.1
194.8	203.7	−4.6
194.8	200.7	−3.0
177.3	179.7	−1.3
153.2	144.8	5.5
145.7	138.7	4.8
131.5	128.2	2.5
83.8	85.4	−1.9

Note: Average difference = 1.51%; SE = ±0.96.

TABLE III. EXAMPLES OF OXYGEN CONSUMPTION OF BUFFALOES PULLING CARTS IN COLOMBIA AS MEASURED BY THE OXYLOG

Live weight (kg)	Standing O_2 consumption (L/min)	Distance walked (m)	Work done (MJ)	Total O_2 consumption (L)	Total measurement time (min)	Elapsed working time (min)
625	1.4	1127	0.5	349	118	19
805	1.8	1293	0.4	467	122	25
750	1.7	913	0.15	390	144	18
650	1.8	2005	1.3	618	157	44
760	2.1	815	0.2	468	162	26
740	1.8	785	0.6	347	90	20

system. To do this a cow was fitted with the Oxylog and all the exhaust gases from the mask and the Oxylog were passed into the open circuit system. Since the response of the latter to changes in O_2 concentration is relatively slow, each determination was made for at least 30 min. Under these conditions the results from the two methods agreed quite well (Table II).

Since these adaptations were made the Oxylog has been used successfully to measure O_2 consumption of working oxen in Nepal (Fig. 5) and of buffalo pulling carts in Colombia (Table III).

However well breath by breath analysers work in a technical sense, they present at least two intrinsic problems. The first is simply that many animals do not like wearing masks, however well designed and however little they impede the animal's breathing. In Nepal, readings were obtainable only from three out of six animals. Similar acceptance rates applied to the cows in the ILCA project in Ethiopia and the buffaloes in Colombia. The 'failures' either refuse to work steadily when wearing the mask even after repeated, patient attempts over many days or simply refuse to move altogether. Another problem is presented by animals that pant to keep cool. This means that although the ventilation rate through the mask goes up, the O_2 consumption remains fairly constant. The result is that the O_2 decrement in the airstream goes down, sometimes by as much as a factor of 2 (Fig. 7), and can reach values that are too low to measure accurately.

4.3. The metabolic rate monitor

The metabolic rate monitor (MRM), a portable flow-through meter designed by Webb and Troutman [21], has been shown to be accurate in the continuous measurement of O_2 consumption in humans, and might prove useful if it could be adapted for measurement of O_2 consumption of draught animals in the field.

The MRM consists of a mask through which air is drawn by a pump. The speed of the pump is controlled by a feedback loop activated by two polarographic O_2 sensors, one of which is in the airstream entering the mask and the other in the airstream leaving it. The loop adjusts the speed of the pump so that the difference in O_2 concentration is maintained at a fixed value (usually 1%). The method depends on having a pump which provides an airflow rate directly proportional to the power supply voltage. Total airflow and hence total O_2 consumption can then be found by integrating the applied voltage with respect to time and making suitable corrections for temperature and humidity of the airflow.

There is a slightly negative pressure in the mask which eliminates the need for it to be airtight. The absence of valves also means that there is virtually no obstruction to the animal's breathing. The accuracy of the instrument in the field, however, might be impaired by wind blowing into the mask or if the animal's breathing interferes with the smooth flow of air through the mask.

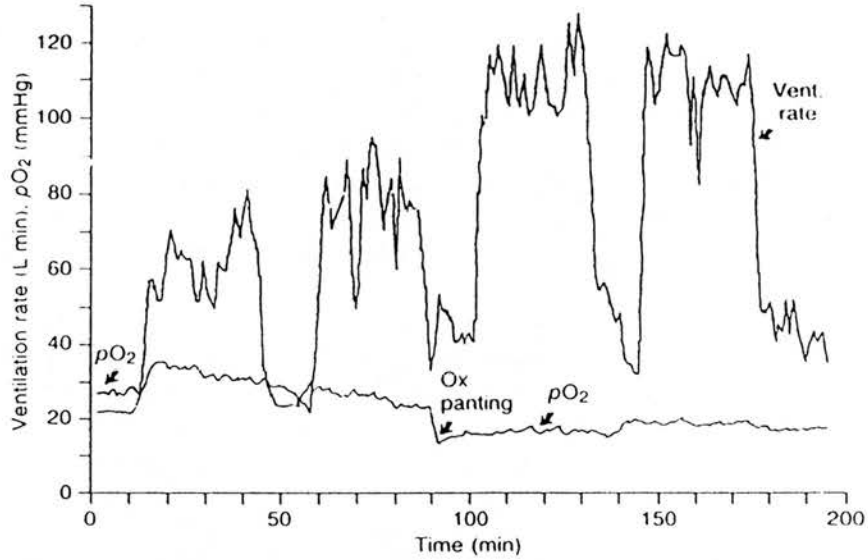

FIG. 7. The effect of panting on the partial pressure of oxygen (pO_2) in the expired air of a hot ox working on a day when the ambient temperature was 10–20°C and the weather cloudy at first and sunny later. (1 mmHg = 133.3 Pa.)

The MRM does not measure ventilation volume, nor does it give the O_2 consumption on a breath by breath basis, but the fact that total flow rate is adjusted automatically to give a constant O_2 decrement means that the instrument is equally accurate at all ventilation rates. The high ventilation rates seen in panting animals could thus be accommodated, making the MRM potentially applicable for use with working animals.

4.4. Tracer methods

4.4.1. Carbon dioxide entry rate

Because CO_2 is continuously produced and excreted, it forms a metabolic pool in the body. If labelled CO_2 is infused into this pool at a constant rate it will eventually reach an equilibrium concentration in the excreted CO_2 which depends on the rate of infusion of the label and the rate of excretion of endogenous CO_2.

If x units of label are infused in one hour and the concentration of label in the excreted CO_2 is y units/L, then the volume of CO_2 excreted in one hour is x/y L or, expressed in terms of rates and concentrations,

$$a = \frac{b}{c}$$

where

- a is the rate of CO_2 excretion;
- b is the rate of infusion of label;
- c is the concentration of label in the excreted CO_2.

This approach has been applied to cattle [22] and sheep [23]. Labelled CO_2 was infused as $NaH^{14}CO_3$ and the concentration of label determined in expired CO_2 or in CO_2 extracted from blood, urine or saliva. In general, comparisons of energy expenditure determined by CO_2 entry rate and by direct measurement of gaseous exchange showed agreement to within 15–20%.

The main intrinsic source of error in the method is that the CO_2 pool of the body is not homogeneous and physiologically consists of several interlinked pools in which the CO_2 turnover rates are quite different. Also, there exist several CO_2 'fixing' reactions which can remove CO_2 from the pool altogether. The errors caused by the inhomogeneity of the CO_2 pool can be minimized by maximizing the length of time during which CO_2 label is infused before sampling starts (Whitelaw [24] recommends 12 h), and the length of time during which samples are taken (24 h). It is important that the metabolic rate of the subject is relatively constant during the sampling period because the turnover rate of the CO_2 pool (once every 1–2 h) is slow compared with the rate at which metabolic rate can change.

This last factor is one of the major objections to the application of this method to working animals. Bakrie [25] found that the method did not compare well with gaseous exchange measurements in working buffaloes. However, his method of measuring gaseous exchange was subject to some problems. The method applied to resting animals has been refined to the extent that the CO_2 output of sheep could be measured to within 2–4% of the values obtained from gaseous exchange measurements [26]. The other major inconvenience of the method is the necessity of continuous and precise infusion of the labelled bicarbonate solution. White and Leng [27] devised a method which involved administering a single dose of labelled bicarbonate but it suffered from the disadvantages that body fluid had to be sampled much more frequently than in the continuous infusion method and mathematical analysis of the results was complex because of the different rates of turnover of the components of the CO_2 pool.

4.4.2. *Double and triple labelled water methods*

The double and triple labelled water methods have not been applied to draught animals but they could be potentially useful.

Hydrogen is lost from the body mainly as water whereas oxygen is lost both in water and as part of the CO_2 molecule. The oxygen atoms in body water and CO_2 are kept in equilibrium mainly owing to the action of the enzyme carbonic anhydrase. If an animal is given a dose of water in which both the hydrogen and oxygen atoms are labelled, the specific activity of the oxygen in the body will decrease faster than that of hydrogen. The difference in the two rates of decrease multiplied by the volume of the total body water (which may be estimated from the initial equilibrium specific activity) will give the rate of loss of CO_2.

The theoretical basis of this double labelled water method was originally worked out by Lifson et al. [28] and has been applied to a variety of animals from mice [29] to men [30].

In practice the method involves giving a dose of water enriched with the two non-radioactive isotopes deuterium and ^{18}O and determining the concentrations of both isotopes at intervals in any body fluid such as saliva or urine. Measurements are taken first of all between 0 and 6 h to determine both the initial concentration of isotope and the total body water and then at intervals until the concentration of isotope has fallen to 25–12.5% of its initial value. In humans this usually means 10–14 d, by which time the ratio of the initial to final concentrations of the two isotopes is large enough to be accurately measured. The rate of loss of CO_2 from the body can then be determined and multiplied by the elapsed time to give the total amount of CO_2 produced.

The main disadvantages of the method are the costs of the isotope enriched water and the highly sophisticated analytical techniques required to determine the isotope enrichment. Also, the method measures CO_2 production only and assumptions have to be made as to the average RQ of the animal if the results are to be used to compute energy expenditure.

The main advantages are that the experimental animal does not have to be restrained in any way and that energy expenditure may be determined over a longer period than is normally possible by respiration calorimetry. Although not suitable for following hourly or daily changes in energy expenditure of draught animals, the method does appear to have a potential use for studying energy expenditure during the bouts of hard work that such animals often have to perform during the cultivation and harvest seasons.

There are, however, several theoretical and practical problems which have to be addressed before attempting to apply the double labelled water method to draught animals. Some of these problems arise because most draught animals are ruminants and others because of the generally large size and high levels of activity of these animals. Fortunately most of these problems have already been solved in other contexts.

The double labelled water method relies on the postulate that hydrogen is lost from the body only as water. In ruminants this is not true since substantial amounts of hydrogen are also lost in methane. Midwood et al. [31] found that the methane produced by sheep given water enriched with deuterium contained only 0.6536 as much deuterium per hydrogen atom as the urine over a wide range of methane production levels. They were thus able to formulate equations which permitted the calculation of CO_2 production provided that reasonable estimates of methane production could also be made. Omission of the methane correction factors would have led to underestimations of CO_2 production of from 3.3 to 6.5% depending on the methane production level.

Another source of error is caused by differential fractionation of isotopes during any physical or chemical equilibrium process involving water. Chief among these processes are the evaporation of water during insensible perspiration, the equilibration of oxygen between water and CO_2 and the evaporation of water from the respiratory tract. Although most of these can be linked to CO_2 production and appropriate corrections made [32], the factor having the largest quantitative effect, the respiratory evaporation of water, can pose problems. This quantity correlates fairly well with CO_2 production in non-panting animals in temperate climates [32] but the same is unlikely to be true of hard working draught oxen in the tropics.

One solution is actually to measure evaporative water loss (insensible perspiration as well as respiratory evaporation) by introducing a third isotope into the water. Haggarty et al. [33] proposed the use of water labelled not only with ^2H and ^{18}O but also with either ^{17}O or ^3H. Tritium is much the cheaper option but has the disadvantage of being slightly radioactive. In the body the different isotopes fractionate to different (known) extents between the liquid and vapour phases during the evaporation of water. In the case of tritium, therefore, the change in the ratio of ^2H to ^3H in the body water can be used to assess the rate of loss of water by evaporation, which in turn can be used to correct for the differential fractionation of the ^2H and ^1H isotopes during the same process. Similar reasoning can be used vis-à-vis the three oxygen isotopes if ^{17}O is used.

Finally, the double labelled water method can be adversely affected by anything which effectively alters the amount of water hydrogen or water oxygen in the body after the start of the experiment. Sequestration of water hydrogen can occur through chemical incorporation into molecules such as proteins and, more especially, fats [34] although this is unlikely to be of importance in adult draught animals which are not growing. Of more likely relevance to studies with draught animals is the possibility of the amount of total body water at the beginning of an experiment being different from that at the end owing to factors such as dehydration.

None of the above problems appear insuperable, in which case the double/triple labelled water method would be potentially useful for the medium term measurement of the energy expenditure of draught animals. However, the method would first have to be proved against more conventional techniques, probably a combination of breath by breath analysis and open circuit chamber calorimetry.

Even with the technical problems removed, the main practical one remains the cost of the labelled water. Although for humans this dropped from an estimated US \$3000 per dose in 1955 [29] to US \$225 in 1982 [30] the cost of dosing draught animals at around US \$1000 a time in sufficient numbers to obtain statistically reliable data remains prohibitive.

4.5. Correlation of energy consumption with heart rate

Good correlations between heart rate and energy expenditure have been achieved in humans within specific limits or for individual subjects [35]. The method has been found to be less reliable in draught animals.

Richards and Lawrence [36] produced a formula for the prediction of energy metabolism from heart rate in regularly trained draught cattle and buffaloes, when heart rate and energy expenditure were expressed relative to their respective resting values:

$$\mathrm{EE} = 24.94R - 16.25 \tag{2}$$

where

EE is the energy expenditure ($W/kg^{0.75}$);
R is the heart rate of the working animal/heart rate at rest.

This equation can be modified to measure energy expenditure over an extended period [8]. If n heart beats are recorded from a working animal in t minutes, the total extra energy used to do the work is:

$$24.94 \times 60 \times M^{0.75} \left(\frac{n - bt}{b}\right) \text{(J)} \tag{3}$$

where

b is the heart rate when the animal is standing;
M is the live weight of the animal (kg).

There are several problems in applying this method to animals in the field. Difficulties occur in assessing a basal heart rate, because of changes during the working period due to changes in fitness, recovery from previous work and anticipation of work to come. 'Calibration' of individual animals could allow more precise estimates of relative heart rate and hence energy expenditure to be obtained provided that facilities are available to 'calibrate' the animals concerned. Even so, animals may not show the same relationship in the field as in the laboratory [37]. Precise measurements of all heart beats over an extended period are technically difficult. Accumulation of sweat dislodges the electrodes and muscle action potentials interfere with the electrical recording apparatus. Even if these problems could be overcome, the confidence limits of Eq. (2) are such that energy consumption can never be estimated very accurately from relative heart rate [8].

4.6. A factorial method

A factorial method based on the extra energy used by draught animals to perform the basic types of movements involved in their work has been developed [38]. This has the following factors:

extra energy used for work =

energy for walking + energy for carrying loads + energy for pulling loads + energy for walking uphill

This formula may be expressed quantitatively as:

$$E = AFM + BFL + \frac{W}{C} + \frac{9.81HM}{D}$$

where

- E is the extra energy used for work (kJ);
- F is the distance travelled (km);
- M is the live weight (kg);
- L is the load carried (kg);
- W is the work done whilst pulling loads (kJ);
- H is the distance moved vertically upwards (km);
- A is the energy used to move 1 kg of body weight 1 m horizontally (J);
- B is the energy used to move 1 kg of applied load 1 m horizontally (J);
- C is the efficiency of doing mechanical work (ratio of work done to energy used);
- D is the efficiency of raising body weight (ratio of work done raising body weight to energy used).

Applications of this formula to the energy expenditure of working oxen have been described [39, 40].

The objection to the use of this formula is that the factors A–D are derived from 'laboratory' experiments in which the animals work under conditions which are often very different from those found in the field. For example, the energy cost of walking is higher when animals walk on muddy surfaces than on hard surfaces [41]. However, the method has the advantage of being easily applicable to fairly large numbers of animals, and the quantities which have to be measured, such as distance travelled and work output, are often of interest for their own sake.

5. CONCLUSIONS

Although there are many methods available for measuring the whole body metabolism of large animals, relatively few have been applied to draught animals.

All the methods mentioned in this paper have inherent problems. Of the gaseous exchange methods, the classic open circuit devices are expensive and complicated to set up and the animals are restricted to a laboratory environment. Currently most effort is being put into portable breath by breath analysers, with three groups of workers having achieved a good level of success. However, such devices are complex and expensive and often difficult to calibrate and repair. Animals often refuse to tolerate wearing a face mask and the devices become inaccurate if the animal pants.

Of the two tracer methods discussed, only that for determining the CO_2 entry rate has been used with draught animals and then with indifferent results. Also, the requirement for the continuous infusion of label renders the method inconvenient for field studies. The double or triple labelled water method would appear to have potential usefulness for measurements lasting two to three weeks and would cause minimal disturbance to the experimental animal. However, there are several theoretical and practical problems which still have to be overcome, not least of which is the cost of the labelled water. Both tracer methods are inherently inaccurate as methods of measuring energy expenditure because they measure CO_2 production and not O_2 consumption.

Measurement of heart rate over any length of time is technically difficult and the results correlate poorly with energy expenditure even under laboratory conditions.

The factorial method also relies exclusively on factors derived from laboratory studies which may not be applicable in the field.

At the time of writing, the use of breath by breath analysers seems the most promising and versatile method for field studies on working draught animals but the choice of methods is wide and unforeseen theoretical and technical improvements may make other methods more attractive in the future.

REFERENCES

[1] MENDELSOHN, E., Heat and Life, Harvard Univ. Press, Cambridge, MA (1964).

[2] LAVOISIER, A., LAPLACE, P.S., Mémoire sur la chaleur, Mém. Acad. R. Sci. (1780) 355–406.

[3] RUBNER, M., Die Quelle der Thierschen Wärme, Z. Biol. **30** (1894) 73-142.

[4] BLAXTER, K.L., The Energy Metabolism of Ruminants, Hutchison, London (1962) 330 pp.

[5] SMITH, A.J., "The role of draught animals in agricultural systems in developing countries", Vegetable Productivity (SPEDDING, C.R.W., Ed.), Macmillan, London (1981) 247-262.

[6] McLEAN, J.A., TOBIN, G., Animal and Human Calorimetry, Cambridge Univ. Press (1987) 338 pp.

[7] BROUWER, E., "Report of the sub-committee on constants and factors", Proc. 3rd Symp. on Energy Metabolism, Troon, 1965 (BLAXTER, K.L., Ed.), Academic Press, London (1965) 441–443.

[8] LAWRENCE, P.R., PEARSON, R.A., "Measurement of energy expenditure in working animals: Methods for different conditions", Draught Animals in Rural Development, ACIAR Proc. Series No. 27 (HOFFMANN, D., NARI, J., PETHERAM, R.J., Eds), Australian Centre for Int. Agricultural Research, Canberra (1989) 155–165.

[9] PETTENKOFER, M., Über die Respiration, Ann. Chem. Pharm. **123** Suppl. 2 (1862) 1–52.

[10] LAWRENCE, P.R., "Facilities for measuring gaseous exchange of large ruminants when working and resting", Draught Animals in Rural Development, ACIAR Proc. Series No. 27 (HOFFMANN, D., NARI, J., PETHERAM, R.J., Eds), Australian Centre for Int. Agricultural Research, Canberra (1989) 330.

[11] MOUNTCASTLE, U.B., Medical Physiology, 13th edn, Mosby, St. Louis, MO (1974).

[12] ZUNTZ, N., LOEWY, A., MULLER, F., CASPARI, W., Hohenklima und Bergwanderungen, Bong, Berlin (1906).

[13] CLAR, U., Entwicklung einer Feldmethode zur Messung des Energieumsatzes bei Zugtieren, PhD Thesis, Univ. of Hohenheim (1991).

[14] HORNICKE, H., et al., "Method for continuous oxygen consumption measurement in exercising horses by telemetry and electronic data processing", Proc. 6th Symp. on Energy Metabolism of Farm Animals (MENKE, K.H., LANTZSCH, H.-J., REICHL, I.R., Eds), EAAP Publ. No. 14, Juris, Zurich (1974) 257–260.

[15] HOWELL, P.J., O'NEILL, D.H., ILCA Contract Final Report, April 1990, Doc. OD/90/05, AFRC Engineering Overseas Division, Silsoe, UK (1990).

[16] HUMPHREY, S.J.E., WOLFF, H.S., The Oxylog, J. Physiol. (London) **267** (1977) 12.

[17] HARRISON, M.H., BROWN, G.A., BELYANIN, A.J., 'The Oxylog'; an evaluation, Ergonomics **25** (1982) 809–820.

[18] WEIR, J.B. DE V., New methods for calculating metabolic rate with special reference to protein metabolism, J. Physiol. (London) **109** (1949) 1–9.

[19] DIJKMAN, J.T., The Oxylog for Oxen, MSc Thesis, Centre for Tropical Veterinary Medicine, Univ. of Edinburgh, Roslin, UK (1989).

[20] LAWRENCE, P.R., DIJKMAN, J.T., "The Oxylog for oxen", Proc. 4th West African Animal Traction Network Workshop, Kano, Nigeria, 1990, ILCA, Addis Ababa (in press).

[21] WEBB, T.P., TROUTMAN, S.J., An instrument for continuous measurement of oxygen consumption, J. Appl. Physiol. **28** (1970) 335–341.

[22] YOUNG, B.A., "Application of the carbon dioxide entry rate to measurement of the energy expenditure by grazing cattle", Proc. 5th Symp. on Energy Metabolism (SCHURCH, A., WENK, C., Eds), EAAP Publ. No. 13, Juris, Zurich (1970) 237–241.

[23] CORBETT, J.L., FARRELL, D.J., LENG, R.A., McCLYMONT, G.L., YOUNG, B.A., Determination of energy expenditure of penned grazing sheep from estimates of carbon dioxide entry rate, Br. J. Nutr. **26** (1971) 277–291.

[24] WHITELAW, F.G., Measurement of energy expenditure in grazing animals, Proc. Nutr. Soc. **33** (1974) 163–172.

[25] BAKRIE, B., Effects of Work on the Environmental Physiology and Digestive Function of Cattle and Buffaloes, PhD Thesis, James Cook Univ. of North Queensland, Townsville (1989).

[26] WHITELAW, F.G., BROCKWAY, J.M., REID, R.S., Measurement of carbon dioxide production in sheep by isotope dilution, Q. J. Exp. Physiol. 57 (1972) 37–55.

[27] WHITE, R.G., LENG, R.A., Carbon dioxide entry rate as an index of energy expenditure in lambs, Proc. Aust. Soc. Anim. Prod. **7** (1969) 335–341.

[28] LIFSON, N., GORDON, G.V., McCLINTOCK, R., Measurement of total carbon dioxide production by means of D_2O, J. Appl. Physiol. **7** (1958) 704–710.

[29] LIFSON, N., McCLINTOCK, R., Theory of the turnover rates of body water for measuring energy and material balance, J. Theor. Biol. **12** (1966) 46–74.

[30] SCHOELLER, D.A., VAN SANTEN, E., Measurement of energy expenditure in human beings by double labelled water method, J. Appl. Physiol. 53 (1982) 955–959.

[31] MIDWOOD, A.J., HAGGARTY, P., McGAW, B.A., ROBINSON, J.J., Methane production in ruminants: Its effect on the doubly labelled water method, Am. J. Physiol. **26** (1989) R1488–R1495.

[32] HAGGARTY, P., The potential of the doubly labelled water method for estimating heat production in farm animals, J. Agric. Sci. (in press).

[33] HAGGARTY, P., McGAW, B.A., FRANKLIN, F.R., Measurement of fractionated water loss and CO_2 production using triply labelled water, J. Theor. Biol. **34** (1988) 291–308.

[34] HAGGARTY, P., McGAW, B.A., FULLER, M.F., CHRISTIE, S.L., WONG, W.W., Water hydrogen incorporation into body fat in pigs: Effect on the double/triple labelled water methods, Am. J. Physiol. (in press).

[35] CHRISTENSEN, C.C., FREY, H.M.M., FOENSTELIEN, E., AADLAND, E., REFSUM, H.-E., A critical evaluation of energy expenditure estimates based on individual O_2 consumption/heart rate curves and average daily heart rates, Am. J. Clin. Nutr. 37 (1983) 468–472.

[36] RICHARDS, J.I., LAWRENCE, P.R., The estimation of energy expenditure from heart rate in working oxen and buffalo, J. Agric. Sci. **102** (1984) 711–717.

[37] BROCKWAY, J.M., WHITELAW, F.G., "Methods of measuring energy in the field", Proc. 5th Symp. on Energy Metabolism (SCHURCH, A., WENK, C., Eds), EAAP Publ. No. 13, Juris, Zurich (1970) 233–236.

[38] LAWRENCE, P.R., STIBBARDS, R.J., The energy costs of walking, carrying and pulling loads on a flat surface of Brahman cattle and swamp buffalo, Anim. Prod. **50** (1990) 29–39.

[39] LAWRENCE, P.R., "The energy expenditure of working oxen", Proc. 4th World Congr. of Animal Feeding, Madrid (1986) 26.

[40] PEARSON, R.A., A comparison of draught cattle (*Bos indicus*) and buffaloes (*Bubalus bubalis*) carting loads in hot conditions, Anim. Prod. **49** (1989) 355–363.

[41] LAWRENCE, P.R., Mud, mud, glorious mud, Draught Anim. News 7 (1987) 1–2.

Printed by the IAEA in Austria

THE MANAGEMENT & HUSBANDRY OF MALE AND FEMALE DRAUGHT ANIMALS: RESEARCH ACHIEVEMENTS & NEEDS.

Richard W Matthewman and **Jeroen T Dijkman**

Centre for Tropical Veterinary Medicine,
University of Edinburgh, Easter Bush, Roslin,
Midlothian, EH25 9RG, Scotland

Ercole Zerbini

International Livestock Centre for Africa,
Addis Ababa, Ethiopia.

Contents

[1] Paper to be presented at the Fourth Workshop of the West African Animal Traction Network entitled 'Research for Development on Animal Traction in West Africa', to be held on the 9 - 13th July 1990, in Kano, Nigeria.

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Richard W Matthewman and **Jeroen T Dijkman**

Centre for Tropical Veterinary Medicine,
University of Edinburgh, Easter Bush, Roslin,
Midlothian, EH25 9RG, Scotland

Ercole Zerbini

International Livestock Centre for Africa,
Addis Ababa, Ethiopia.

Abstract

This paper reviews research findings relevant to draught animal husbandry and management, and highlights the differences in use of oxen and cows for draught. Topics considered include the choice between cows and oxen and effects of work on physiology, metabolism, health, food intake, digestion, bodyweight change and lactation and reproductive physiology in draught cows.

The husbandry and management of draught animals are considered and methods are described which could be adjusted for different draught animal powered farming systems. Aspects covered include duration of work, housing, health care and feeding draught animals. When considering these aspects of husbandry, attention is focussed on the need to optimise the use of farm resources in the search for sustainable farming methods.

A summary of topics deserving more research is given. It is suggested that farming systems research in close cooperation with the local communities is required to determine ways of producing adequate food for draught animals and the establishment of sustainable farming systems.

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Introduction

Draught animals are economically important, but their maintenance involves both risk and capital expenditure to the owner. Their outputs include livestock products as well as increased crop yields and transport facilities. Because of their importance and the demands made upon them, draught animals deserve good care and attention. This will help reduce the risk of loss and make draught animals a more acceptable and reliable innovation. Draught cows in particular require high levels of husbandry input if their overall productivity is not to suffer.

Considerable research has been done on technical aspects of draught animal use such as nutritional requirements, work output and the design of implements. Husbandry aspects and constraints to the adoption, integration and sustained use of draught animals in farming systems have received less attention. Similarly, draught cows and the effect of work on their production have been considered only recently.

This paper reviews research findings relevant to draught animal husbandry. The husbandry of male and female draught animals is considered and suggestions are made for further research.

Choice between oxen and cows for work

Oxen are often the preferred draught animals in tropical farming systems, but cows are used where land and food resources for ruminants are scarce. Where pressure on land is high, large animals tend to be excluded in favour of smaller female animals. Bangladesh is a good example of this inter-relationship, where up to 50% of draught animals are cows (Matthewman and Foulds, 1988). Other situations exist where high pressure on land has reduced food resources for ruminants, such as in Kano State, Nigeria and the Kenyan and Ethiopian Highlands. In Zimbabwe, Tembo (1989) has described how land population pressure and poor exploitation of the available draught oxen has become critical to crop production. It is under such conditions that cows can help to meet the demand for draught power.

Parts of the world where cows are used to provide draught power include Bangladesh (Plate 1), Indonesia, Pakistan, Philippines, Thailand, Sri Lanka, Poland, Senegal, Egypt, Zambia, Zimbabwe, Guadaloup (Plate 2) and others (Nourrissat, 1965; Rollinson and Nell, 1973; Kumaratileke and Buvanendron, 1979; Akhtar, 1981; Lhoste, 1983; Ranjan, 1983; Sasimowski *et al*, 1984; Rep.Zam., 1985; Barton, 1987 and Matthewman, 1987 and 1988).

[Plates 1 and 2 near here].

An advantage of using cows for work is that male animals can be slaughtered at a more optimum time. Also, draught cows, when they produce milk and calves, are capable of using food energy more efficiently than oxen. In addition the total number of animals needed to maintain the "draught herd" is significantly lower than when oxen are used (Smith, 1981). Disadvantages are that cows cannot work in late pregnancy and their work output may be lower than that of bigger oxen. The nutrient requirements for work may interfere with growth, lactation and the reproductive cycle, because it is often difficult to provide enough high quality food to meet the demands of these functions.

The use of cows almost presupposes conditions of scarce or declining resources. It is under these circumstances that research is needed to find methods of stopping the downward spiral of resource availability on small farms. Where conditions are approaching those where under other circumstance cows are used, on-farm research is needed to determine the feasibility and constraints to the introduction of the use of cows.

Effects of work on physiology and metabolism

Exercise and work have many effects on physiological and metabolic functions. The consequences include short-term stress, increased metabolic rate (short-term), increased energy and nutrient requirements and changes in the ratio of blood metabolites characterised by a drain on blood glucose and acetate, the depletion of glycogen reserves and the stimulation of free fatty acid mobilisation. The replacement of body stores after work is associated with short-term increase in metabolic rate. It has been shown that the metabolic rate of animals after work remains high until reserves of glycogen and energy yielding metabolites such as free fatty acids and tryglycerides have been replaced (Lawrence *et al*, 1989). Nutrient requirements will be increased as a result of this. When animals work they become fitter. This involves increased cardiovascular rate, increased muscle tone, changes in lean to body fat ratio, effects on digestive function and reduced long-term metabolic rate. As they become fitter and better co-ordinated they use less energy, which can partly off-set the increased metabolic rate discussed above.

Different types of draught animals will respond in different ways to the effects of work. Research can help farmers and extension staff devise husbandry practices to allow draught animals to meet the demands of work and overcome some of the adverse effects.

The effect of work on the health of draught animals

Draught cattle suffer the normal health problems of other cattle. Recent publications such as Kehoe and Chan (1987) in Malaysia and Kenyon *et al.* (1989) in Indonesia discuss the general health problems of draught animals. Work also may have direct effects on health, some beneficial and some detrimental. Little published information exists however, about these direct effects.

Stress, caused by poor husbandry or overwork, can pre-dispose to other health problems (Munzinger, 1982). In untrained animals, stress is characterised by increased body temperature, increased respiration rate, fatigue and energy expenditure to maintain homeostasis. Starkey (1981) describes how the balance between parasite and host may breakdown if the host is overworked or underfed. Munzinger (1982) distinguished two types of ailments, those resulting directly from work, such as wounds, sprains, tendonitis and inflamed hooves and those resulting from increased susceptibility induced by work and for which natural premunity or tolerance can quickly disappear under stress, such as trypanosomiasis and tick-borne disease.

A discussion of stress related to draught animals is given by Wells (1986) who described the stages of the syndrome as - alarm, resistance and exhaustion - which can result in a depressed immune response. Stress apparantly gives rise to increased susceptibility to normally avirulent bacteria, the activation of latent viruses and a poor response to vaccines. If protein nutrition is deficient this can supress immunoglobulin production. Wells considers stress to have been the cause of increased incidence of haemorrhagic septicaemia in Asian cattle and buffaloes at the beginning of the rainy season. The same stressors are thought to predispose to trypanosomiasis (*T. evansi*) in working buffalo in north Vietnam (Wells, 1986). In West Africa were zebu draught cattle are often used at the fringes of tsetse belts, similar problems may occur. Starkey (1982) discusses the health problems of trypanotolerant N'Dama draught cattle in Sierra Leone, which also can reduce or lose their tolerance under stress.

Further research will have to point out the exact parameters which cause stress, but in the majority of the cases proper preventive health measures and the maintenance of a reasonable physical state of the animals should reduce health problems precipitated by work to a minimum.

Evidence from Nepal (Pearson, R.A. personal communication) has suggested that work precipitates latent helminth infections in draught buffaloes, which reduced their work output significantly, but preliminary research in Edinburgh (Sewell, M.H.H. personal communication) did not demonstrate a causal link between work and susceptibility to helminths in sheep exercised on treadmills.

The effect of work on food intake

On roughage diets, intake is related to the amount of digesta in the reticulo-rumen and the rate of passage through the tract. For diets containing more concentrate, intake is limited by other factors including thermostatic and chemostatic regulation. Ruminants can adjust intake to meet requirements in a similar way to monogastric animals, provided the physical and chemical properties of the food do not impose limitations (Forbes, 1983). Hence the animal's current physiological state plays a part in determining food intake. Work increases food intake in horses and rats (Weston, 1985), and it might be supposed that work also increases food intake in ruminants. This has been investigated by a number of researchers.

No increase in intake was demonstrated by Henning (1987) who exercised sheep on treadmills, Barton (1987) in Bangladesh who worked bullocks over a seven week period and Lawrence (1985) in Costa Rica who found that intake in oxen was virtually the same when they worked as when they were idle. The animals in these trials must therefore, have lost weight.

Ffoulkes (1986) however, found a positive effect of work on food intake in an experiment using 16 female buffaloes fed a diet of a 1:1 mix of coursely chopped rice straw and natural pasture grass, amounting to an increased energy intake of 9.8MJME/d. Winugroho (1988) in Indonesia found a increase in food intake (25%) in mature female buffaloes fed a 50:50 diet of *ad libitum* chopped fresh road-side grass/rice straw. Bamualim *et al*, (1987) and Bamualim and Ffoulkes (1988) in further experiments reported no effect of work on food intake. Bakrie *et al*, (1988), using six steers fitted with rumen cannulae, were unable to show an increase as a result of work. Again, animals which did not eat more must have lost weight.

The nutrient demands of lactating cows permit these animals to eat 35-50% more than non-lactating animals of the same weight and on the same diet (ARC, 1980). This factor could be exploited if cows are used for draught purposes.

Since the animals in all these experiments were fed on poor quality diets, it would be interesting to see if the same results are obtained when animals are fed on higher quality diets.

The effect of work on digestion

Ffoulkes (1986), Ffoulkes *et al*, (1987) and Winugroho (1988) reported increases in digestibility in working buffaloes (13%, 6% and 12% respectively). Light exercise may be beneficial causing greater mixing of the rumen contents which may enhance microbial fermentation. Higher levels of work might have more detrimental effects, caused by a shift in blood supply from the gut to muscles and peripheral tissues.

Other authors (Kibet and Hansen, 1985; Weston, 1985; Astatke *et al*, 1986) have discussed the effects of exercise on digestion and have found either no effect or negative effects. Negative effects may be associated with other factors such as restricted dietary regimes in these trials.

Although most research suggest that work does not increase digestion or food intake in draught animals, it remains to be fully determined whether this is the case. In practice efforts will have to be directed to the optimalisation of the dietary regime, within the resources available, to ensure the maintenance of a good physical state of the animals.

The effect of work on body weight change

Astatke *et al* (1986) found that both food restricted animals and animals fed to 100% of requirement lost weight (between 4 - 17%) when working for five hours/d over 23 weeks. Winugroho (1988) found that working female buffaloes lost weight (18kg whe working 6 hours per day for 39 days) compared to non-working animals. In subsequent trial (Winugroho *et al*, 1989) reported weight losses of 19, 9 and 5kg for female swamp buffaloes on different dietary regimes compared to gains of 19, 20 and 7kg for control animals in the same groups.

Ffoulkes (1986) measured reduced weight gains and slight weight losses in working (W) and non-working (C), non-pregnant buffaloes measured over 120 days and fed either on 100% (M) or restricted (R) diets of rice straw and grass. Weight changes for CR, CM, WR and WM were +110g/d, +326g/d, -6g/d and +79g/d.

Matthewman *et al* (1989) found that lactating, pregnant cows which were exercised for three hours a day for three weeks either lost weight or did not gain weight as quickly as control animals. Weight gains after the exercise were higher than before exercise or during exercise. This might be explained by replacement of gut-fill. Increases in serum free fatty acid and serum beta hydroxy butyrate levels were recorded, indicating mobilisation of body tissue reserves during exercise.

Observations at the C.T.V.M. have indicated that well fed animals increased in body weight at the start of a working period, as fat was being replaced by muscle tissue.

The loss of weight should not necessarily be regarded as a bad consequence. If the animals are able to regain their weight within a reasonable period, "working off their back" could well improve their overall efficiency. Care however has to be taken with this attitude as this only applies to animals which are in relatively good condition at the start of the working period.

The effect of work on the productivity of draught cows

a) *Lactation*

Glucose has been identified as a nutrient which may act as a constraint on work or other productive functions in ruminants (Leng, 1985). Glucose is not usually an end product of digestion in ruminants and little glucose is absorbed from the gut. Sugars ingested into the rumen are quickly broken down by microbes and ruminants derive most of their glucose from precursors such as propionate and amino acids. Propionate production is encouraged by feeding diets with a greater proportion of concentrate, rather than roughage diets which promote acetate as the end product of fermentation. Leng (1985) suggests that glucose availability may constrain work, particularly in growing animals or productive females. This may be true despite the animal's ability to to synthesise glucose at differential rates according to productive function.

Glucose is essential for lactose synthesis and for certain other functions. The rate of milk secretion is related to the osmotic properties of lactose and is proportional to the rate of secretion of lactose (Rook and Hopwood, 1970; Rook and Wood, 1959).

A number of authors have stated that if cows are well fed work will have no effect on milk yield. Research on European dual purpose breeds showed no drop in milk yield in cows in good condition (Krautforst, 1947). Rajapurohit (1979) noted that in Egypt work neither had ill effects on the milk yield or health of working cows. Munzinger (1982) states that in Senegal the weight development of Djakore calves whose mothers were used for draught power production and received a working ration, was significantly better than that of calves whose mothers did not work - and presumably did not receive a 'working ration'. The most plausible explanation of this is that the farmers took greater care of their working animals.

Little study has been made of the effect of work on lactation in working cows or female buffaloes. Evidence suggests that when cows work, daily milk yields decline and milk composition is affected. Research carried out in Edinburgh (Matthewman *et al*, 1989; Matthewman *et al*, 1990) has shown that exercise affects both milk yield and composition. 12 lactating and pregnant cows walked approximately 9 km/d for three weeks (maximum 15 to 17 hours per week or 45 to 51 hours over three weeks) and walked at average speeds of 2.9 km/h. Milk yield was depressed by 7 to 14%. Animals were fed to requirement on diets of known composition. The decline was associated with milk composition changes, which indicated that the decline was not due simply to an energy deficit, but also to the supply of specific nutrients. Milk fat yield (g/d) was not affected by exercise, but lactose and milk protein declined by the same proportion as milk yield. Milk fat concentration (g/100g milk) therefore increased, but milk protein and lactose concentrations remained the same.

The above results for milk yield agree with those of Rizwan-ul-Muqtadir *et al*, (1975) who found that work caused a 14% drop in milk yield in buffaloes fed a ration containing 13% DCP given according to requirement. They ploughed three hours a day at speeds of between 2.1 and 2.9 km/h. Other authors (Jabbar, 1980; Kibria, 1982; Goe, 1983) have reported that exercise affects milk yield, but did not specify levels of reduction.

Barton (1987) found that over a five week working period, cows in Bangladesh in the second month of first lactation lost between 23 and 40% of the milk yield. These animals ploughed for two or three hours a day (maximum of 19 hours per week or 95 hours over five weeks) at average speeds of 2.2km/h. They were fed *ad libitum* alkali treated or untreated rice straw with 1kg fresh grass and 300g concentrate. Tornede (1939) reported that in cows ploughing in pairs for up to eight hours a day in Germany, could cause up to an 80% fall in milk yield. It has to be mentioned however, that the actual length of the working period and time of feeding could seriously influence the intake and time left to eat and ruminate.

Although milk yield declines during exercise, yields have been shown to return to previous levels when animals are rested for two days after five days of exercise (Matthewman *et al*. 1989).

Diet may influence the response to exercise. Cows in Edinburgh were fed diets of different composition to provide different glucose precursor to determine whether glucose availability constrains lactation in working cows. The diets either provided high levels of propionate (from barley), amino acids from undegradable protein (fish meal) or starch digested in the small intestine (from ground maize). It was found that diets which promoted high levels of rumen fermentation supported lactation better than other diets. Such diets would be recommended for working cows. Recent reseach at ILCA suggest that working crossbred cows receiving concentrate supplements show a bettter milk production persistency then non-supplemented animals. Barton (1987) found that cows fed alkali treated rice straw had a lower reduction in milk yield than cows fed untreated straw. Ffoulkes (1986) however, recommended providing nutrients which are non-fermentable and digested in the small intestine, to reduce weight loss in female draught buffaloes.

b) *Reproductive Physiology*

The effects of work on reproduction in draught cows have been little researched, though numerous reports have been published which offer speculation as to the effects. Work carried out in early lactation could delay return to oestrus and reduced blood sugar levels resulting from work could affect implantation if work was carried out around this time (Macfarlane, J. S., personal communication). Bamualim *et al* (1987) reported preliminary observations on the effect of work on ovarian activity in 16 non-pregnant swamp buffaloes which worked 2 hours/day for 5 days a week for 12 weeks. The animals were offered fresh chopped rice straw and grass (1:1) *ad libitum* with a salt supplement. Blood samples for plasma progesterone assay were taken as a measure of ovarian activity. This was categorised as negative, doubtful or positive. Of the eight non-working cows, 6 were positive, 1 doubtful and 1 negative, compared with 2 positive, 2 doubtful and 4 negative in the working group in the last four weeks of the experiment. This indicated an important negative effect on ovarian activity due to work.

Weight losses resulting from work may be associated with reduced reproductive efficiency. Teleni *et al*, (1989) concluded that a loss of approximately 17% of liveweight was detrimental to reproductive function. These animals were in good condition and lower levels of loss might have detrimental effects in animals in poorer condition.

A study conducted by ILCA (Agyemang *et al.*, 1985) on the effect of work on productive and reproductive performance of crossbred dairy cows in the Ethiopian highlands indicates that work had no significant effect on milk production, lactation length, days open, calving interval and services per conception when animals received adequate feeding and only worked for short periods.

THE HUSBANDRY OF DRAUGHT ANIMALS

Much of draught animal husbandry and management is the same as for other animals, but there are special features which include the following:

- draught animals have to be able to work when they might be least able to do so (ie at the end of dry season)
- husbandry practices (eg vaccinations, mating of draught cows) will have to timed in conjunction with work requirements
- work can cause stress and predispose to further health problems
- draught animals are therefore more vulnerable to illness
- veterinary care will be required at specific times
- some specific health hazards of work
- good foot care is required
- draught animals need to be easily handled and used to human beings

- draught animal husbandry requires a greater labour input (for feeding, cut and carry)
- draught cow nutrition is more complex than for oxen
- draught animals may suffer heat stress.

Seasonal use of draught animals

A regular routine of work should be maintained outside the cultivation period. Draught animals should be used for carting in the dry season, rather then regrouping them with the grazing herds as is common in West Africa. This will keep them trained and reduce stress at the start of the new growing season. Draught cows have the advantage that if they are regularly milked, this contact will help to keep them tractable. Farmers, however, might consider the maintenance of such a routine an unnecessary demand on their time and effort. The positive impact of increased effort on family income needs to be demonstrated.

Duration of work

The amount of work expected from an animal should be determined by the food input, the condition of the animal and stage of lactation and pregnancy in females. If necessary animals should not be worked every day, but the more work that an animal performs, the more efficient it is. Starkey (1981) found that well fed oxen could work 4 - 5 hours per day for five days a week. Little is known whether heat affects work output, but the preferred time to work is in the cooler parts of the day (7 - 11am; 5 - 7pm). If condition is being lost, the work load must be reduced or significant supplementary feeds must be given. In temperate regions animals can work for 6 - 8 hours per day, presumably as a result of cooler conditions and better food inputs. It might be possible to extend the working period in the tropics if animals are fed higher quality diets and when greater advantage is taken of the cool parts of the day, thereby reducing the problems encountered as a result of heat stress.

Lawrence (1986) has described the methodology for calculating the amount of work and the duration of work that could be expected from an ox on particular diets if the animal is not to lose weight.

Housing

Because of their value, draught animals offer one of the best ways of introducing improved animal husbandry methods to local farmers. A simple shelter or lean-to would provide the necessary protection from rain. Shelters should have a sloping floor to allow run-off to keep them dry and clean, and dung should be removed daily to reduce the problem of flies. Good hygiene is essential and more harm than good can be caused by allowing houses or shelters to become dirty. Houses should be periodically disinfected and clean bedding provided. Troughs for food and water should be provided.

Health Care of draught animals

Pearson (1986) makes the important point that little benefit will be gained from better feeding, training and improved harnessing and implement design if health is neglected. Care is required to prevent stress and susbsequent loss of health to ensure the animal can carry out timely work. For draught animals, prevention, rather than cure, is certainly the best approach.

Draught animal husbandry should be as stress free as possible. If animals are handled frequently, stress caused by contact with human beings will be negligible. Animals should be groomed (washed and brushed) and inspected daily for wounds, skin infections, signs of harness rubbing and ticks. Hooves should be inspected and trimmed as necessary.

Prior to the main cultivation season attention should be given to health and condition to ensure that animals will be able to complete the work necessary. Since stress can arise because of poor nutrition, attention at this time to building up body condition is important.

Good vaccines are available against rinderpest, anthrax, black quarter contagious bovine pleuropneumonia, haemorrhagic septicaemia, pasteurellosis and tetanus, and drugs are available for protection against trypanosomiasis. It should be born in mind that vaccinations should be given at a time that work stress does not interfere with the immune response. Animals should be tested for tuberculosis, brucellosis, trypanosomes, piroplasmosis, Johne's disease and helminths. Cattle can be sprayed strategically against ticks using hand sprays or washing. Routine drenching against round worms and flukes is recommended, particularly where animals are working in wetter areas.

Ectoparasites such as as lice can be treated with insecticides. Brushes should also be treated to stop the spread of mange. Ringworm, which is more common in younger animals, can be treated with tincture of iodine daily on the lesions. Wounds and scratches can predispose to other infections such as streptothricosis and should be washed and disinfected. Healing ointment will help protect the wound and keep flies off.

Proper nose rings should be used rather than rope to reduce irritation and laceration of the nasal septum. Horn injuries from tight ropes and neck and shoulder injuries from harnesses can easily be avoided by careful attention to harnessing methods. Ropes and harnesses should be disinfected regularly. Attention should be given to the possible dangers and causes of lameness in the locality where animals work or graze. Stones and earth can become stuck in the hoof, as well as thorns and other sharp objects. Strains and sprains need complete rest.

Feeding draught animals

The nutrient requirements of draught animals have been described by Mathers (1982), Lawrence (1985), Pearson (1986) and Teleni and Hogan (1989). The main energy metabolites which supply working muscles are acetate, free fatty acids and glucose. Acetate is the main energy substrate for resting muscle, but when animals work, free fatty acids become more important and glucose utilisation is increased (Bird, Chandler and Bell, 1981; Pethick, 1984). Other sources of energy for muscular work include glycerol and the glycogen present in body tissues. In mature oxen, requirements for work would only compete with maintenance for metabolites, but in female lactating and/or pregnant cattle greater competition for metabolites could occur. Energy requirements depend on maintenance energy required (MJME/d), which is related to body weight (MAFF, 1975), and also to rate of growth, type of work, other productive outputs (eg. conceptus and milk) and environmental conditions.

At normal levels of work, cattle usually expend between 150% (Barton, 1987) and 175% (Starkey, 1981) of maintenance energy expenditure. While energy demands for work can be substantial, work appears to have little effect on urinary nitrogen excretion and the demand for protein for increased muscle metabolism for work is considered to be negligible. There is no evidence that work significantly affects vitamin requirements, but it has been demonstrated that work can reduce blood levels of minerals such as magnesium and phosphorus (Agarwal *et al*, 1982; Pearson and Archibald, 1989). Mineral supplements can help to improve productivity in all classes of livestock. In cattle in West Java, Winugroho (1989) reported a 90% increase in liveweight gain in weaners, 28% in lactating cows and 76% in working cattle fed a mineral supplement compared with unsupplemented animals. In hot climates animals may need extra salt to replace that lost in sweat. A calcium supplement such as dicalcium phosphate is also recommended to help bone development.

If an ox is not growing it will require to eat enough food to meet maintenance and the requirement for work. For a 400kg ox working at 1.75 times maintenance this would be approximately 76MJME/d. For a 400kg pregnant (3 months) cow doing the same work and producing 3 litres of milk a day, the energy requirement would be approximately 95MJME/d (see figure 1).

Natural vegetation will provide such requirements only at certain times of the year. Work done in the Ethiopian highlands indicates that the energy content of dry roughages range from 6 to 7 MJME/kg. In addition most mature dry and green forages are found deficient in phosphorus and sodium (Bediye and Sileshi, 1989). The types of food available for draught animals in West Africa include natural pasture (young, mature, senescent or standing hay), browse and tree leaves, fruits of trees (eg. *Acacia albida* and *A. tortilis* pods) crop residues, agro-industrial by-products, concentrates from crops such as cotton and groundnuts, grain millings, blood meal, fish meal, cereal grains, urea, molasses, salt and mineral supplements. Conserved roughages such as hay and silage are not commonly used in many parts of the tropics. Hence, application of new techniques and research findings to conserve part of the abundance of natural forage during particular periods of the year need further attention. Roughage treatment with alkalis such as sodium hydroxide or ammonium hydroxide derived from urea, have application and have been demonstrated to improve the nutritive value of poor quality roughages.

Draught animals are most called upon at the beginning of the wet season when food resources are poor. Strategic "work flushing" one month before the start of this period would reduce the problems normally encountered.

The timing of feeding during the day and the number of feeds when animals are working should allow the animal to consume as much food as possible. The better the quality the diet, the better the intake.

It is important to weigh animals regularly so that food provision can be adjusted to requirements. Weigh bands which measure the heart girth are a good alternative to weighing, but should be calibrated for the particular breed. Condition score is a useful way of gauging the animal's nutritional status.

The application of the gained knowledge to an African farmers' situation will often be obstructed by a lack of resources. With reference to the prevailing climatic conditions, one could however draw up a husbandry calender based on the food energy requirements. Routinisation of draught animal husbandry will not only simplify their use in the farming operation, but it will in addition insure that the appropiate measures are carried out at the right time. An example of this is shown in figure 1.

[Fig. 1 near here]

Sustainable systems

To ensure the best use of the scarce research funds, the needs of farmers and farming communities must be determined. The sustainability of systems depends on the balance of inputs and outputs. The power and manure draught animals provide reduce the need for oil powered machines and fertiliser. In this respect considerable gain can be derived from keeping draught animals on the farm all year round and operating a cut and carry system of feeding. The net input of nutrients and the resulting benefits from dung to the productive farm land by cut and carrying fodder can be considerable. If draught animals graze on non-farm land, the benefit would be lost.

As ruminants, draught animals are able to convert otherwise non-utilisable food resources into animal products. In addition, the reduction of the human workload allows more time for other farm activities, such as cut and carrying fodder. Research into the more effective use of animals for these roles deserves a high priority.

Although the introduction of animal traction in most instances led to an improved agricultural production, the actual increase has often arisen from an extension of the cultivated area rather than significantly higher production per hectare. It has to be stressed that the introduction of draught animal power can only be justified if long term methods can be devised which optimise the use of the available resources, rather than a short term maximalisation of production. The use of fallow land for cut and carry purposes or as in the case of Nigeria a better use of the fadamas should be researched.

In farming system where draught power has been employed for a number of years, similar paths will have to be followed to relieve the increasing pressure on the environment. Further research into the optimalisation of the productivity and efficiency of the draught cow under different sustainable systems will have to be encouraged.

Future research needs

In areas where draught animals are used, farmers should be encouraged to make the greatest possible use of their animals for farm work and transport. The more work that draught animals do, the greater the efficiency of use of the inputs required to support them. Extension programmes backed by sound on-farm research are required to determine ways of optimising the value of draught animals to the farmers who own them. It has to be realised that only when farmers see the benefits of their increased work load will they accept and apply new husbandry strategies.

The relationship between work, stress and ill health requires further elucidation, with attention given to the strategic requirements of draught animals to allow them to provide draught power at the crucial times in the farming calendar.

The requirements of male draught animals and oxen are relatively straight forward. Work could double the maintenance energy requirement and food consumption must be high enough to meet these requirements if the animal is not to lose weight. Farming systems research is therefore required to determine ways of producing adequate food for draught animals on the farm and to determine types of locally available supplements which might provide an adequate diet.

The nutritional requirements of female draught animals are more complicated and research is required to determine the types of local food which can best support lactation and pregnancy as well as work. The complementary roles of diets which promote rumen fermentation and those which promote digestion in the small intestine deserve attention.

The effect that work and exercise have on voluntary food intake, rate of passage and digestion is at present not clear. This topic requires more clarification.

In West Africa there is increasing pressure on land for cultivation and other human activities and this places increased pressure on food resources for draught animals. Although oxen are the preferred draught animal, there is much evidence that smaller draught animals, such as small breeds and cows, can carry out the same farm work as larger oxen. Research into the potential use of cows for cultivation and transport is required.

Only when we can find sustainable longterm solutions in cooperation with the farming communities will people be prepared to overlook the short term benefits of ecological destructive farming methods. The real challenge lies in the application of the gained knowledge for the establishment of sustainable farming environments. •

References

Agarwal, S.P., Singh, N., Agarwal, V.K. and Dwaraknath, P.K. 1982. Effects of exercise on serum electrolytes and their relationship in entire, castrated and vasectomised male buffaloes. Indian Vet. J. 59: 181 - 184.(E).

Agyemany, K., Abiye Sotatke, Anderson, F.M. and Woldeab, W. M. 1985. Early indications of effect of work on reproductive performance of crossbred dairy cows in the Ethiopian Highlands. Highland Programme Working Document. International Livestock Centre for Africa.(E).

Akhtar, A.S. 1981. Draught animal power as a source of renewable energy in Pakistan. Asian Livestock, *6(2)*: 13.(E).

ARC 1980. The nutrient requirements of ruminant livestock. Commonwealth Agricultural Bureaux, Farnham Royal.(E)

Astatke, A., Reed, J.D. and Butterworth, M.H. 1986. The effect of diet restriction on work performance and weight loss of local Zebu and Friesian x Boran crossbred oxen. ILCA Bulletin 23, ILCA, Addis Abbaba.(E).

Bakrie, B., Murray, R.M. and Hogan, J.P. 1988. The effect of work on intake and rumen fluid volatile fatty acid and NH_3 concentration of steers fed Rhodes grass hay. Draught Animal Power Project Bulletin, *7*: 9 - 13. December, 1988. James Cook University, Townsville, Australia.(E).

Bamualim, A., Ffoulkes, D. and Fletcher, I.C. 1987. Preliminary observations on the effect of work on intake, digestion, growth and ovarian activity of swamp buffalo cows. Draught Animal Power Project Bulletin, *3*: 6 - 10. August, 1987. James Cook University, Townsville. Australia.(E).

Bamualim, A. and Ffoulkes, D. 1988. Effect of work and level of food intake on nutritional parameters and body weight change of swamp buffalo cows. Draught Animal Power Project Bulletin, 7: 2 - 8. December, 1988. James Cook University, Townsville, Australia.

Barton, D. 1987. Draught power supply, nutrition and the work output of draught animals in Bangladesh. A report prepared for the Ford Foundation, Diaka, Bangladesh.(E).

Bedive, S. and Sileshi, Z. 1989. Feeding value of some Ethipian feedstuffs. IAR Proceedings. 2nd National Livestock Improvement Conference. 24 -26 February 1987. Addis Ababa, Ethiopia. pp. 111 - 113.(E).

Bird, A.R., Chandler, K.D. and Bell, A.W. 1981. Effects of exercise and plane of nutrition on nutrient utilisation by the hind limb of sheep. Aust. J. Biol. Sci., *34*: 541 - 550.(E).

Ffoulkes, D. 1986. Studies on working Buffalo - current research on nutritional aspects. Balai Penelitian Ternakliawi, Bogor. Draught Animal News. 6. CTVM. University of Edinburgh.(E).

Ffoulkes, D., Bamualim, A. and Panggabean, T. 1987. Utilisation of fibrous feeds by working buffaloes. In: The utilisation of fibrous agricultural residues as animal feeds. Ed. R. Dixon. Melbourn. University of Melbourn Printing Service.(E).

Forbes, J.M. (1983) Models for the prediction of food intake and energy balance in dairy cows. Liv. Prod. Sci., *10*: 149- 1571.

Goe. M.R. 1983. Current status of research on animal traction. World Animal Review, *45*: 2 - 17.(E).

Henning, P.H. 1987. The effect of increased energy demand through walking exercise on intake and ruminal characteristics of sheep fed a roughage diet. J. Agric. Sci. Camb., *109*: 53 - 59.(E).

Hoffmann, D. and Dalgliesh, R.J. 1985. A multidisciplinary approach to health and disease in draught ruminants. ACIAR Proceedings No. 10. pp 134 - 139. Ed. W.W. Copland, James Cook University, Queensland. (E).

Jabbar, M.A. 1980. Draught power shortage and mechanisation of tillage in Bangladesh. Bengal J. Agric. Econ. *3*: 1 - 26.(E).

Kehoe, M.M. and Chan, L.C. 1987. Buffalo draught power on oil palm estates. The Incorparated Society of Planters, Kuala Lumpur, Malaysia. (E).

Kenyon, S., Fauzi, S., Burton, R. and Darsana, R. 1989. Health in Draught Animals: An example from West Java, Indonesia. ACIAR Proceedings 27. Draught animals in rural development. pp 212 - 215. Eds. D. Hoffmann. J. Nari and R.J. Petheram. James Cook University, Townsville, Australia.(E).

Kibet, P.K.F. and Hansen, R.M. 1985. The effect of walking while grazing on rumen digestion. East African Agricultural and Forestry Journal. *51*: 30 - 35.(E).

Kibria, Q.C. 1982. Draught animal power for crop production and use of cows. Maximum production from minimum land. Proceedings of the third seminar held at Mymensyngh, Bangladesh.(E).

Krautforst, J.W. 1947. Influence of work balanced by food on the efficiency of cows. Animal Breeding Abstracts, *16*: 115. 1948.(E).

Kumaratileke, W.L.J.S. and Buvanendron, V. 1979. A survey of production characteristics of indigenous buffaloes in Sri Lanka. Ceylon Veterinary Journal, *27*: 10 - 13.(E).

Lawrence, P.R. 1985. A review of the nutrient requirements of draught oxen. ACIAR Proceedings No. 10 Ed. W.W. Copland, James Cook University, Queensland. (E).

Lawrence, P.R. 1986. Nutrition of working animals. In: An introduction to working animals. Ed. J.Lindsay Falvey. MPW Melbourne, Australia.(E).

Lawrence, P.R., Buck, S.F. and Campbell, I. 1989. The metabolic rate of oxen after work. Proceedings of the Nutrition Society. *48*: 153A.(E).

Leng, R.A. 1985. Muscle metabolism and nutrition in working ruminants. ACIAR Proceedings No. 10 Ed. W.W. Copland, James Cook University, Queensland.(E).

Lhoste, P. 1983. Development de la traction animale et evolution des systems pastoraux au Sine Saloum, Senegal. (1970 - 80). Rev. Elev. Med. Vet. Oays. Trop., *36*: 291 - 300.(F).

MAFF 1975. Energy allowances and feeding systems for ruminants. Technical Bulletin 33, Ministry of Agriculture, Fisheries and Food, HMSO, London.(E).

Mathers, J.C. 1982. Nutrition of draught animals. Paper presented at the FAO expert consultation on appropriate use of animal energy in agriculture in Africa and Asia. FAO. Rome.(E).

Mathers, J.C., Pearson, R.A., Sneddon, C.J., Matthewman, R.W. and Smith, A.J. 1985. The use of draught cows in agricultural systems with particular reference to their nutritional needs. In: Milk production in developing countries. Ed. A.J. Smith, University of Edinburgh Press, Edinburgh.(E).

Matthewman, R.W. 1987. Role and potential of draught cows in tropical farming systems: A review. Tropical Animal Health and Production, *19*: 215 - 222.(E).

Matthewman, R.W. 1988. Draught animals and the role and future potential of draught cows in African farming systems. In: The explotation of animals in Africa. Ed. J.C. Stone, Proceedings of a colloquium at the University of Aberdeen, March 1987, pp 101-112.(E).

Matthewman, R.W., Merrit, J.B., Oldham, J.D., Phillips, P. and Smith. A.J. 1989. Effects of exercise on lactational performance in cattle. Proceedings of the Nutritional Society, *48*: 92A.(E).

Matthewman, R.W., Smith, A.J., Pearson, R.A., Phillips, P. and Oldham, J.D. 1990. The effect of sustained exercise on milk yield. milk composition and blood metabolite concentrations in crossbred Hereford x Friesian cattle. In preparation.(E).

Matthewman, R.W. and Foulds. A.B. 1988. Draught animal power in Bangladesh: A review of literature. CTVM Miscellaneous Report. University of Edinburgh.(E).

Munzinger. P. 1982. Animal traction in Africa. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ). Eschborn. W.Germany.(E).

Nourrissat, P. 1965. Etudes et traveaux la traction bovin en Senegal. Agronomie Tropical (Paris). *20*: 823 - 853.(F).

Pearson, R.A. 1986. Feeding and management of draught animals: a review. Indian J. Anim. Prod. Mgmt.. *2*: 48 - 49.(E).

Pearson, R.A. and Archibald, R.A. 1989. Biochemical and haematological changes associated with short periods of work in draught oxen. Anim. Prod. *48*: 375 - 384.(E).

Pethick, D.W. 1984. Energy metabolism in skeletal muscle. In: Ruminant physiology: concepts and consequences (Eds. S.K. Baker, J.M. Gawthorn, J.B. MacKintosh and D.B. Purser). University of Western Australia, Perth. pp. 277 - 287.(E).

Rajapurohit, A.R. 1979. Cross-breeding of Indian cattle: An evaluation. In: Economics and Political Weekly. A Sameeksha Trust Publication.(E).

Ranjan, S.K. 1983. Carabaos in the Philippines: Priorities for research and development. World Animal Review, *46*: 26 - 36.(E).

Rep.Zam. 1985. Draught animal power. Investment Plan Task Force, Planning Division, MAWD, Lusaka, Zambia.(E).

Rizwan-ul-Muqtadir, R.A.G., Ahmad, M. and Ahmad, Z. 1975. Draught power and its effect on milk yield and milk composition in lactating buffaloes during the winter season. Pakistan J. Agric. Sci. *12*: 93 - 98.(E).

Rollinson, D.H.L. and Nell, A.J. 1973. The present and future situation of working cattle and buffaloes in Indonesia. UNDP/FAO Project INS/72/009. FAO, Rome.(E).

Rook, J.A.F. and Hopwood, J.B. 1970. The effects of intravenous infusions of insulin and sodium succinate on milk secretion in the goat. J. Dairy Res., *37*: 193 - 198.(E).

Rook, J.A.F. and Wood, M. 1959. Potassium and lactose in milk in relation to the physiology of milk secretion. Nature, London,. *184*: 647 - 648.(E).

Sasimowski, E., Slomka, Z. and Halewicz, Anna 1984. The use of dairy cows for draught purposes in Silesian Poland. Draught Animal News 2, CTVM, University of Edinburgh.(E).

Smith, A.J. (198) The role of draught animals in agricultural systems in developing countries. In: Vegetable Productivity (Ed. C.R.W. Spedding), pp. 247 - 262. London: Macmillian.

Starkey, P.R. 1981. Farmimg with work oxen in Sierra Leone. Report of the Sierra Leone Work Oxen Project. Ministry of Agriculture, Tower Hill, Freetown.(E).

Starkey, P.R. 1982. N'Dama cattle as draught animals in Sierra Leone. World Animal Review. *42*: 19 - 26.(E).

Teleni, E. and Hogan, J.P. 1989. Nutrition of draught animals. ACIAR Proceedings 27. Draught animals in rural development. pp 118 - 133. Eds. D. Hoffmann, J. Nari and R.J. Petheram. James Cook University, Townsville, Australia.(E).

Teleni, E., Boniface, A.N., Sutherland, S. and Entwistle, K.W.

1989. The effect of depletion of body reserve nutrients on reproduction in *Bos indicus* cattle. Draught Animal Power Project Bulletin, *8*: 10. August, 1989. James Cook University, Townsville, Australia.(E).

Tembo, S. 1989. Draught animal power research in Zimbabwe: Current constraints and research opportunities. ACIAR Proceedings 27. Draught animals in rural development. pp 61 - 68. Eds. D. Hoffmann, J. Nari and R.J. Petheram. James Cook University. Townsville, Australia.(E).

Tornede, H. 1939. The problem of work performance of dairy cows with special reference to hill cattle. Zuchtungskunde, *14*: 308 - 333. Animal Breeding Abstracts, *8*: 230. 1940.(E).

Wells, E.G. 1986. Health of working animals. In: An introduction to working animals. Ed. J.Lindsay Falvey. MPW, Melbourne, Australia.(E)

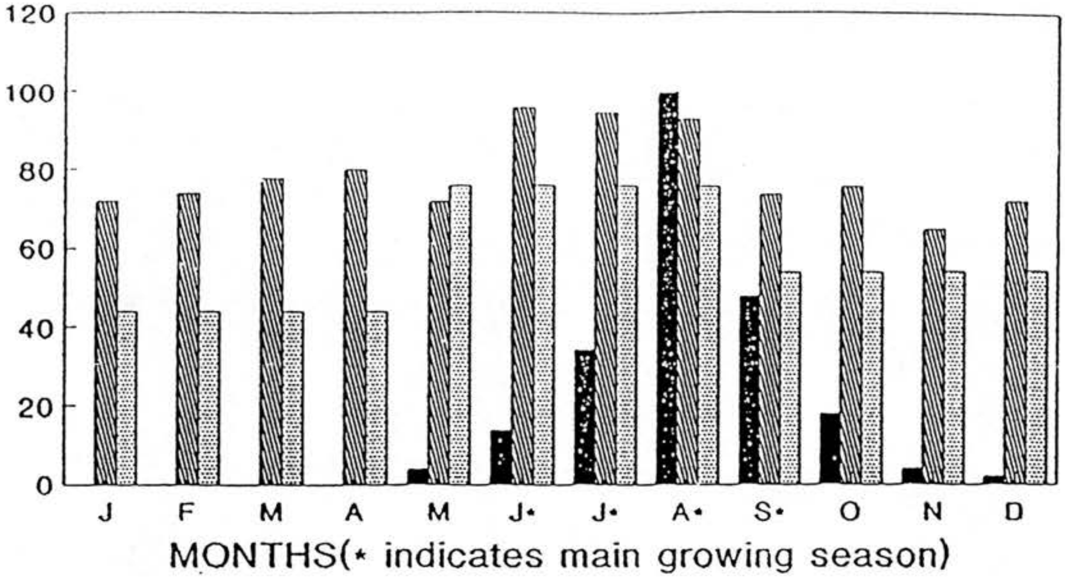
Weston, R.H. 1985. Some considerations of voluntary food consumptuion and digestion in relation to work. ACIAR Proceedings No. 10 Ed. W.W. Copland, James Cook University, Queensland.(E).

Winugroho, M. 1988. The effect of work durations on voluntary food intake and digestibility, liveweights and physiology of buffaloes fed a grass:rice straw diet. Paper presented at the Congress of the Sixth Federation of Asian Veterinary Associations (FAVA), October 16 - 19, 1988, Depasar, Bali.(E).

Winugroho, M. 1989. Mineral supplementation to working buffalo and cattle grazed on field grasses in Subang. West Java. Draught Animal Power Project Bulletin, *9*: 19. August. 1989. James Cook University, Townsville, Australia.(E).

Winugroho, M., Juwarini, E. and Teleni, E. 1989. The effect of work on liveweight losses in buffaloes of different body conditions. Draught Animal Power Project Bulletin. *8*: 9. April. 1989. James Cook University, Townsville, Australia.(E).

Energy requirements (MJME/d) + husbandry calendar of draught cattle



Work flush cows + oxen			x	x								
Mating period				x	x							
Pregnancy diagnose									x	x		
Calving period	x	x										
Wean calf								x	x			
Supplement cows									x	x	x	x
Supplement calf								x	x	x	x	x
Deworming				x	x							
Dipping/spraying				x	x	x	x	x	x	x	x	x
Vaccinations	x	x								x	x	x
Check hoofs			x	x	x	x	x	x	x			
Weigh/record	x	x	x	x	x	x	x	x	x	x	x	x
Conserve surp. forage							x	x	x	x		

Rainfall(mm/5) MJME/d for cow MJME/d for ox

• NB. seasonal rainfall area

Comments: 400 kg ox and 400 kg cow: Energy requirements cow are built up from maintenance, pregnancy, milk and work output. Ox is used for light transportation work after the cultivation period.